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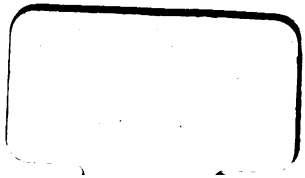

RUDIMENTARY TREATISE

ON

MARINE ENGINES

AND

STEAM VESSELS;

TOGETHER WITH

Practical Remarks

ON THE

SCREW AND PROPELLING POWER

AS USED IN THE ROYAL AND MERCHANT NAVY.

By ROBERT MURRAY, C.E.,

ENGINEER-SURVEYOR TO THE HON. BOARD OF TRADE.

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PREFACE TO THE THIRD EDITION.

UPWARDS of five years having elapsed since the revision of this Treatise, much of the matter contained in the last edition had already become obsolete, and many corrections and additions were found wanting, to keep pace with our extended experience of screw propulsion, and with the advance which has meanwhile been made in our acquaintance with steam ships in general.

The Author will only repeat what he says in the Preface to the First Edition, that he trusts the book may prove useful to the various classes of practical men employed and interested in our steam marine, whether in the Royal Navy or Merchant Service; and with this end in view, he still endeavours to explain what he has to say in as practical and concise a manner as possible.

In the Appendix, and generally throughout the book, will be found much new and useful information relative to the details and performances of our most successful steamers.

The data from which these Tables are compiled have been all supplied, in the most liberal spirit, either by the manufacturing engineers who made the machinery, or by the officers of the companies who own the vessels, to whom the Author returns his grateful acknowledgments.

Southampton, August 1, 1857.

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No. 2 is a longitudinal section through the engine room, showing an end view of two cylinders, the valves, steam pipes, starting apparatus, screw shaft, and geared wheels.

No. 3 is a longitudinal section through the boiler room, showing the fronts of the boilers, the furnace mouths, telescopic funnel, and jointed steam pipes, the various decks and hatchways, etc.

No. 4 is a cross section through the boiler room, showing the sides of the boilers, the stoke place, the steam pipes, and winches for raising the telescope funnel.

THE

MARINE STEAM ENGINE.

CHAPTER I.

GENERAL DESCRIPTION AND VARIETIES OF THE MARINE ENGINE.

A previous Acquaintance with the Principles of the Steam Engine presupposed.—As this little work professes to be a guide to the management of marine engines and steam vessels, and not a treatise on the steam engine, it will be necessary to presuppose a certain degree of knowledge of the facts and mechanical principles on which the structure and operation of steam engines depend. In short, to take it for granted that the reader has perused either Dr. Lardner's Rudimentary Treatise, in this series,* or some other work on the same subject. This being understood, we shall proceed at once to the consideration of the marine engine of the present day, as it is found in vessels of the Royal Navy and merchant service.

General Description of the Marine Engine.—The principles upon which the marine engine is constructed, as well as its general plan of operation, are identical with those of the stationary or land condensing engine; the motive power in both

* Rudimentary Treatise on the Steam Engine, by D. Lardner, LL.D. John Weale. 1*s.*

being derived from the pressure of the steam acting against partial vacuum. Thus we have in each case a *boiler* to generate the steam; a *cylinder*, *piston*, and *valves* to use it; *condenser* in which to condense it, and thereby gain the pressure of the atmosphere by causing the steam to work against a vacuum; and lastly, an *air pump* to withdraw the condensing water, the condensed steam, and the uncondensed vapour, and gaseous matter. Such are the principal parts of every condensing or "low-pressure" steam engine, whether it be used on land or at sea; whether it be side-lever, direct-acting, oscillating, horizontal, or rotatory.

Varieties of Form.—The terms last used are those employed to designate different forms of the marine engine which have been imposed upon it by wants and necessities of various kinds. For as the services which steam vessels are called upon to perform are very different, so also must be their machinery, in order to suit the proposed mode of propulsion, the required form and displacement of the hull, the minimum draught of water, the comparative value of stowage or of passenger accommodation, the necessity of protection from shot, the efficiency of the armament, and a hundred other considerations which may enter into the plans of a steamer.

In all marine engines the required object is to give a rotatory motion to a horizontal shaft—either the paddle shaft in the case of paddle-wheel steamers, or the screw shaft in the case of vessels propelled by the screw. The earliest form of engine used for this purpose was the side-lever, or beam engine, in which the reciprocating motion of the piston rod is transferred through upright side rods and horizontal side levers to the connecting rod, which then gives the shaft its continuous rotatory motion by means of the crank.

The Fly Wheel not applicable.—If such an engine were used to drive machinery on shore, it would be furnished with a fly wheel, which, by becoming a reservoir of momentum, would

supply power to continue the rotatory motion past the top and bottom of the stroke, where the crank is evidently (from its nature) powerless, and in this way a uniform speed would be maintained throughout each revolution of the shaft. But in the case of a vessel at sea, the fly wheel is inadmissible. Considerable irregularity in the revolutions results from this want, but not to such an extent as to be attended with any bad results. In some engines where the moving parts are not arranged so as to balance each other in their ascent and descent, one part of the stroke is made at a greater velocity, but this is generally obviated by admitting a greater quantity of steam on one side of the piston than on the other, until the propelling power for the up and down strokes accords with the resistance. The air-pump bucket is generally arranged in such a manner, that by its ascent it may balance the weight of the piston in the cylinder in its descent.

Advantage of using two Engines.—Hence arises the necessity for supplying the place of the fly wheel by combining two engines on one shaft, in such a manner that when the one engine is at its *least* effective point (at the top or bottom of the stroke) the other engine may be *most* effective—each alternately helping the other over its difficulties.

Single Engines sometimes employed.—River steamers, however, are occasionally fitted with only one engine, the moving parts of which are "balanced" (by means of a cast-iron paddle board, or otherwise) in such a manner as may best assist the crank in passing the centres; but such an arrangement is always objectionable from the difficulty experienced in starting, and from the impossibility of preventing a disagreeable jumping motion in the vessel from the unequal speed at which the paddle wheels are driven.

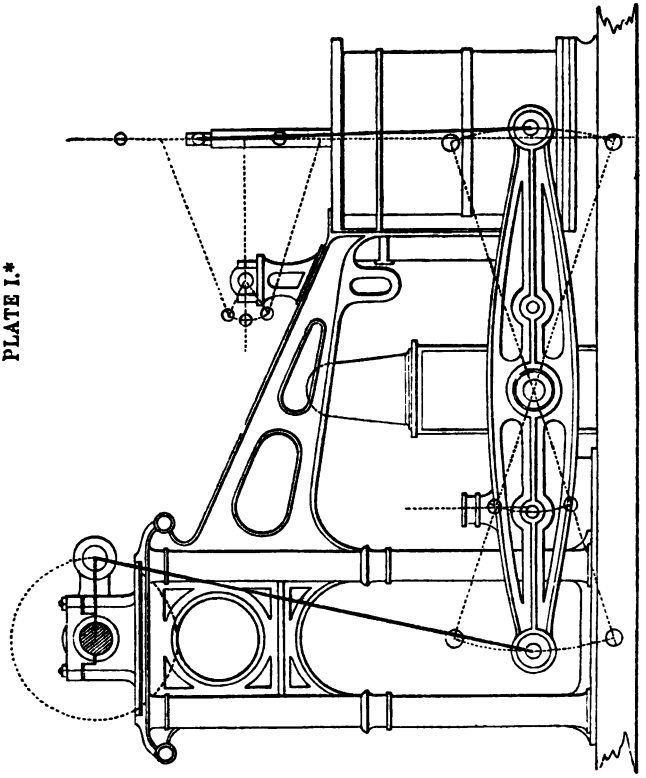
High-pressure Engines rarely used.—High-pressure engines are very rarely put into steamers in this country, the objec-

tions to their use being their increased consumption of fuel in comparison with condensing engines, and the presumed danger to passengers, arising from explosion or escape of steam, which has made them extremely unpopular. As they possess, however, the countervailing advantages of cheapness and lightness, they have been adopted in some cases where economy of fuel is not so much considered as first cost and light draught of water. While referring hereafter to the marine engine, it should be understood that the *condensing engine* alone is meant.

Side-lever Engine—its Advantages.—It has been said that the side-lever engine was the first employed in steam boats. This construction, with the arrangement of which the reader is doubtless familiar, has several advantages, which enabled it for a long while to resist innovation. Perhaps its chief merit consists in this, that the weights of the moving parts are so balanced, the one against the other, that the piston when not acted on by steam is nearly *in æquilibrio*, and equally ready to start in either direction with the smallest application of force. The great length of the connecting rod, also, admits of the motion of the piston being transmitted to the crank in the most equable and effective manner, and the moving parts of the engine are supposed to do their work with less friction and wear than are to be met with in any other kind of engine. It can hardly be wondered at, therefore, that the side-lever engine was long a favourite, and indeed that it still continues to be so in certain cases, and under certain conditions. An example of a side-lever engine is given in Plate 1.

Disadvantages of the Side-lever Engine.—There are two very important conditions, however, in the economy of a sea-going steamer which the side-lever engine *does not* fulfil,—namely, lightness of weight, and compactness of form. As these properties were found to be most essential in the machinery of a war steamer, it soon became apparent that some other arrangement of parts must be adopted which would admit of the

PLATE I.*



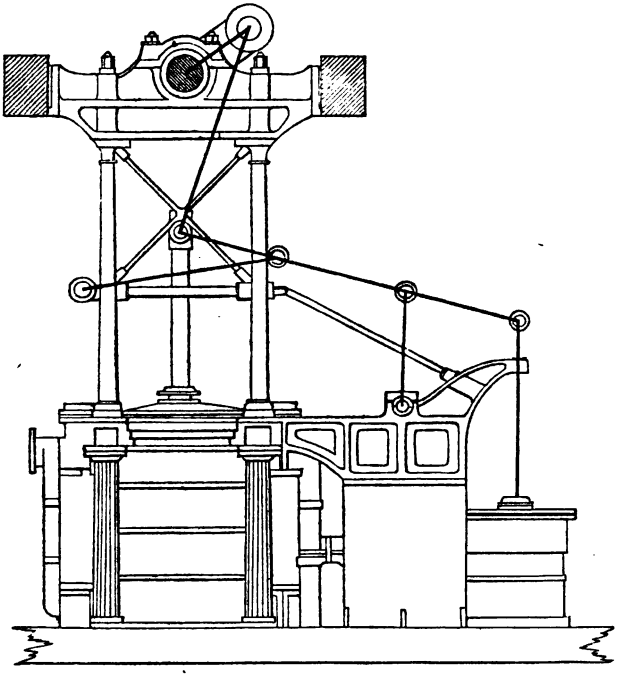
* For examples, see Tredgold on the Steam Engine, new edition.

same power being stowed in less compass, and a p the weight of the machinery saved for additional stores, or armament.

Adoption of the Direct-acting Engine.—Hence the ada tion and general use of direct-acting engines in the Roya Navy, by which means (in conjunction with the adoption of tubular boilers) the length of the engine room was diminished by about one-third, and the total weight of machinery by two-fifths. It may be observed here, that the weight usually allowed for side-lever engines, flue boilers with water, and paddle wheels, is one ton per horse-power; whilst direct-acting engines with tubular boilers and water, paddle wheels, etc., scarcely exceed 12 cwt. per horse-power. The distinguishing feature of all direct-acting engines consists in the connecting rod being led at once from the head of the piston rod to the crank without the intervention of side levers; and as it happens (unfortunately, we think) that this kind of engine is capable of almost endless variety, each manufacturing engineer has introduced his own child into the steam navy, where scarcely two pairs of direct-acting engines are to be found alike.

Varieties of the Direct-acting Engine.—These may be all classed under three heads; namely, those which obtain the parallelism of the piston rod by means of the system of jointed rods called a "parallel motion;" those which use guides or sliding surfaces for this purpose; and those denominated "oscillating engines," in which the cylinder is hung upon pivots and follows the oscillations of the crank. Belonging to the first class are those of Seaward, Rennie, Fairbairn, Forrester; and to the second class, Maudslay, Miller, Fawcett, Boulton and Watt, Bury, Robert Napier, Joyce, etc. As these various arrangements cannot be rendered intelligible in words, sketches of some of the most characteristic are subjoined, in Plates 2 to 10.

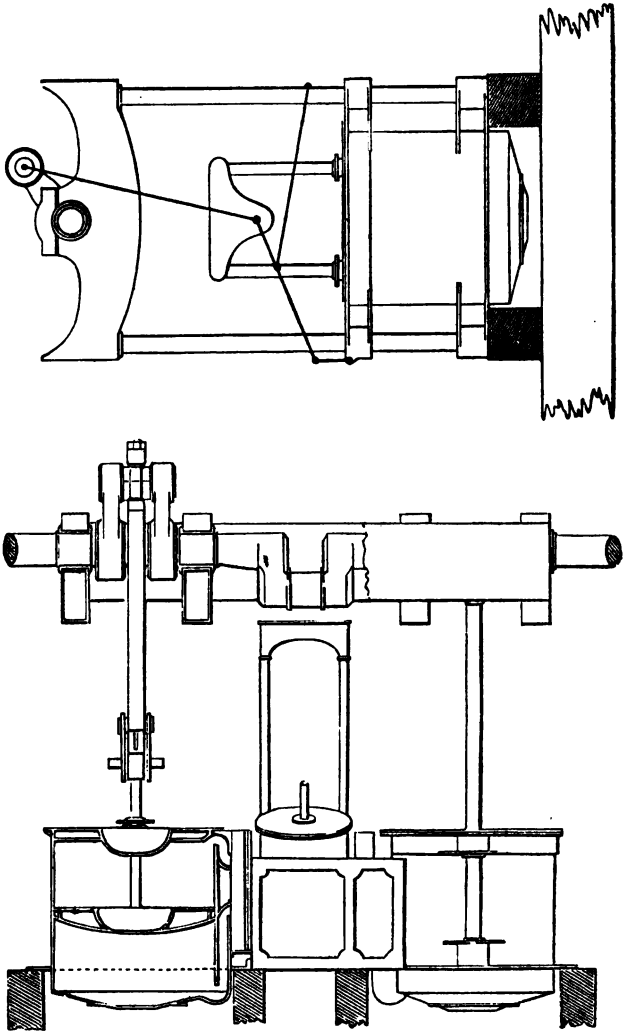
PLATE II.



Direct-acting Engine, as constructed by MESSRS. SEAWARD, CAPEL, & Co.*

* See pages 8 and 9; and for full details of the engines of the *Cyclops* see the Appendices to Tredgold.

PLATE III.



Direct-acting Engine of 500 *H. P. of H. M. S.* Bull-dog, *constructed by* MESSRS. RENNIE.

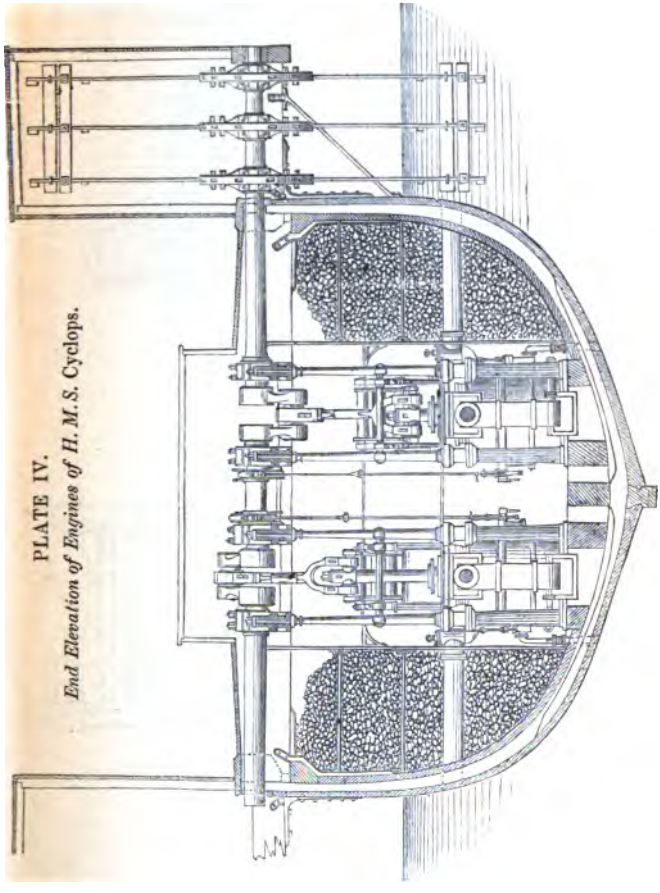


PLATE IV.

End Elevation of Engines of H. M. S. Cyclops.

PLATE V.

Elevation of Main-lever of Parallel Motion of H. M. S. Cyclops.

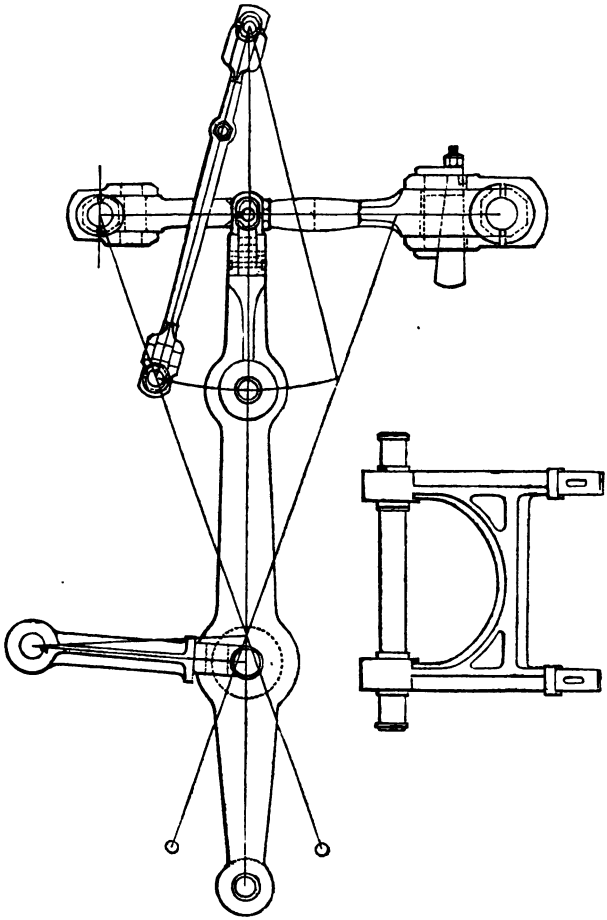
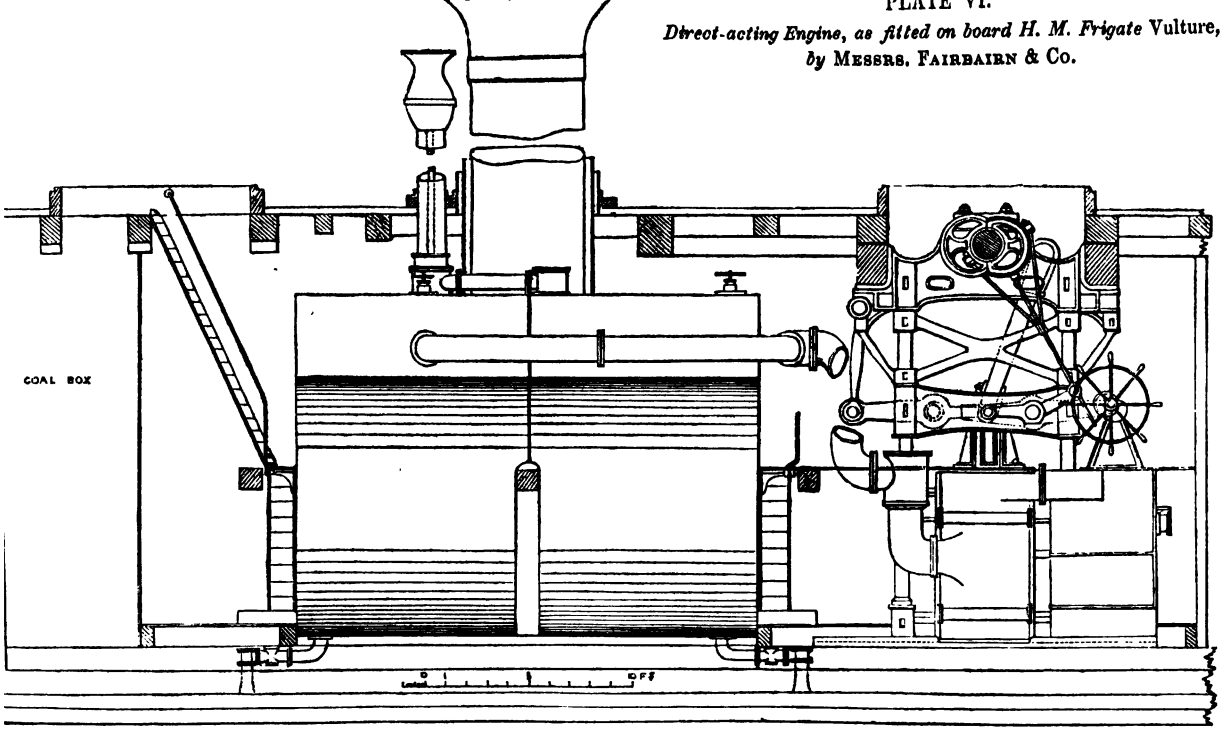


PLATE VI.

Direct-acting Engine, as fitted on board H. M. Frigate Vulture, *by* MESSRS. FAIRBAIRN & Co.



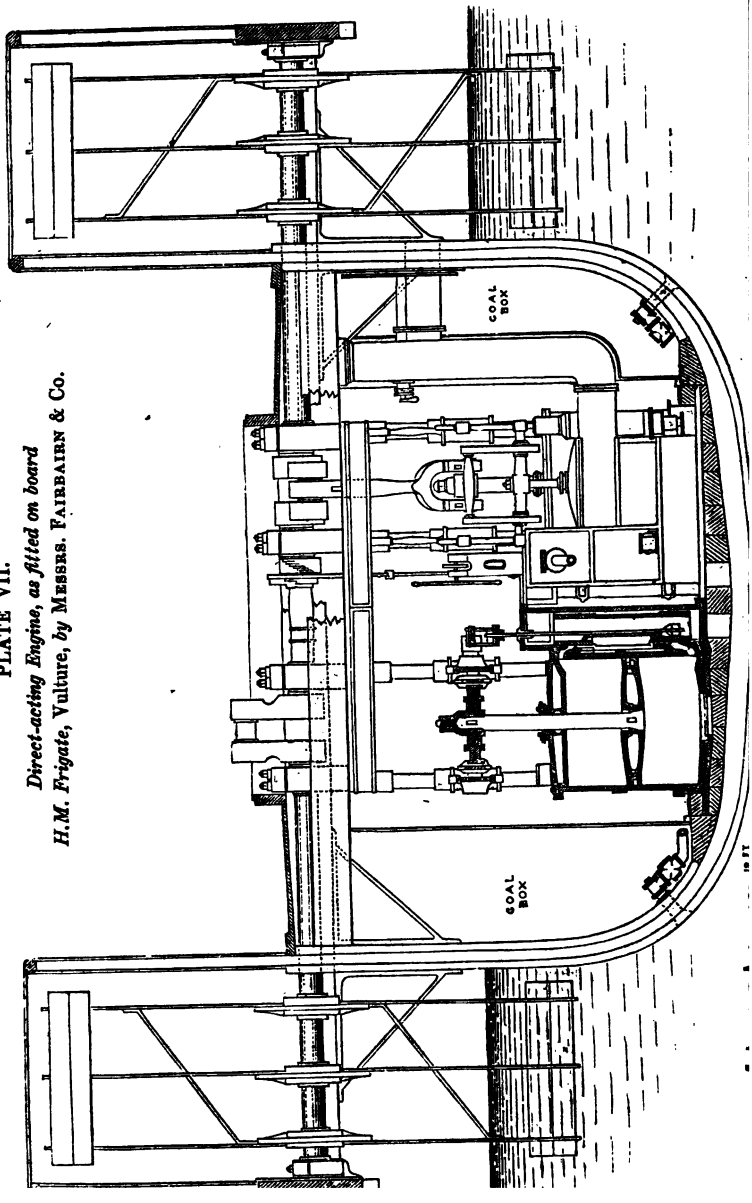
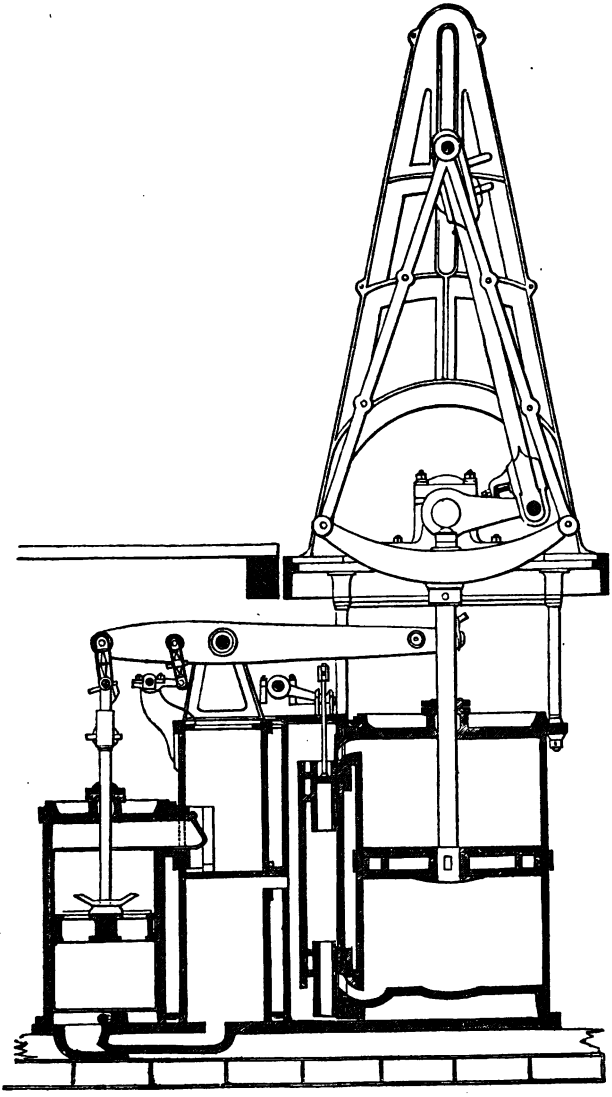


PLATE VII.

Direct-acting Engine, as fitted on board
H.M. Frigate, Vulture, *by* Messrs. Fairbairn & Co.

PLATE VIII.



Marine Engine of the Rainbow *Iron Steam Vessel, constructed by* MESSRS. FORRESTER & Co., *Liverpool. See Appendices to Tredgold.*

Shortness of Stroke a Defect.—The unavoidable shortness of the stroke and of the connecting rod in the majority of direct-acting engines is certainly a defect, and becomes sensible in practice by the increased wear and tear of brasses and packings, and a greater consumption of tallow and oil when compared with the old side-lever engines. Several of the direct-acting varieties, it is true, are not necessarily confined in the length of stroke,—as, for instance, the "steeple engine," which is such a favourite in America, as well as on the Clyde.

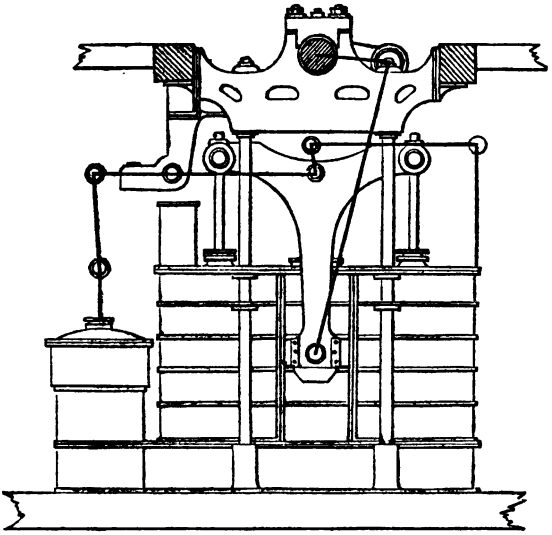
Steeple Engine.—The latter, deriving its name from the high erection on deck required by the guide to the connecting rod which works *above* the crank shaft, can be recommended only in the case of river steamers, where the increased height of the centre of gravity, and the increased surface exposed on deck to the action of the winds and the waves, are not so detrimental as would be the case in a sea-going steamer. See page 13, a successful example. She made, notwithstanding, very rapid passages between London and Antwerp.

Double-cylinder Engine. — Maudslay and Field's double-cylinder variety also makes a good engine, and may have tolerably long stroke and connecting rod, but for small powers it is heavy and expensive. It also occupies more space in the engine room than several other kinds of direct-acting engines; but for very large powers, where the excessive diameter of a single cylinder may be considered objectionable, it appears to be most applicable, and has indeed proved itself to be highly efficient. See Plate 9.

Trunk Engines.—In this description of engine a hollow cylindrical casing, or "trunk," is fastened to the upper face of the piston, this casing being made to slide steam-tight through the cylinder cover in the same manner as the piston rod in an ordinary engine. The lower end of the connecting rod descends through the hollow trunk to the upper side of the piston, to

which it is jointed, the top of the connecting rod being connected as usual with the crank pin. Thus neither piston rod nor parallel motion are required, since the connecting rod has space to vibrate within the hollow trunk. The effective area of the piston is of course diminished by the area of the trunk, the surface of the piston within the steam cylinder being annular where the trunk is attached. These engines are frequently used for driving the screw propeller, for which they appear very suitable, the cylinders being in this case placed horizontal, and the trunk projecting through the bottom of the cylinder as well as the top, in order to equalize the area for pressure, and support the weight of the piston.

PLATE IX.

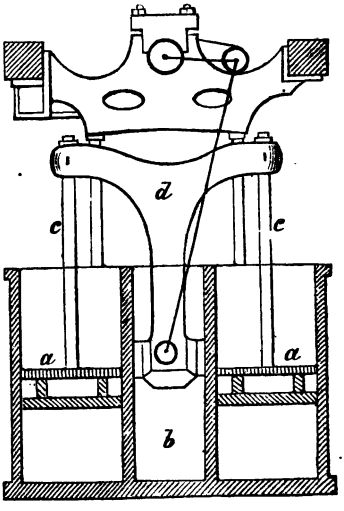


Direct-acting Double-cylinder Engine, as constructed by MESSRS. MAUDSLAY, SONS, & FIELD.*

Annular Engine.—In this variety the piston is made in the form of a ring, *a*, *a*, encircling an inner cylinder, *b*.

* See Tredgold, new edition, Division B, Marine Engines.

Two piston rods, *c*, *c*, communicate the reciprocating motion to the hollow cross-head *d*, which descends into the inner cylinder, where it is jointed to the lower end of the connecting rod. The latter slides between vertical guides on the face of the internal cylinder, the head of the connecting rod being in connection with the crank pin, as usual. The advantage to be derived from this arrangement is, that a long connecting rod is thereby obtained without unduly increasing the height of the paddle shaft. Messrs. Maudslay's annular engines in the *Courier*, *Express*, and *Despatch*, carrying the mails to Guernsey and Jersey, are favourable specimens of this kind of engine.



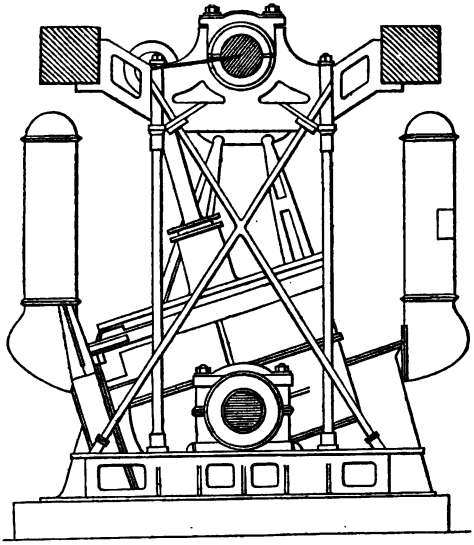
Annular Engine.

Atmospheric Engine.—The peculiarity of this engine consists in the principle of condensation and vacuum being made use of for the descending stroke only, the ascending stroke of the piston being made by the simple pressure of the steam acting against the pressure of the atmosphere. In this arrangement the cylinder is left open at the top, and no piston rod is required, the connecting rod being jointed directly to the upper face of the piston. Engines of this description (employing three steam cylinders) have been recently fitted by Messrs. Seaward in several steamers belonging to the South-western Steam Navigation Company, where they have given much satisfaction.

Oscillating Engine.—Of all the direct kinds, however, the

oscillating engine, which has derived from Mr. Penn so much of its elegant simplicity and present perfection of workmanship and arrangement, is generally preferred. It need hardly be explained that this engine derives its name from the fact of the cylinders "oscillating" upon hollow axes or "trunnions," through which the steam is admitted to, and withdrawn from, the valves,—the piston rod by this means accommodating itself to the motion of the crank without any "parallel motion" being required. This construction has now been proved as applicable to ocean steamers as to the small boats on the Thames, where it has long been a favourite; and it appears to be also well adapted for driving the screw propeller.

PLATE X.



Oscillating Engine, as constructed by MESSRS. JOHN PENN & SON.*

Machinery for Screw Propulsion.—The introduction of propulsion by the screw has brought into use many other modifications of the marine engine, in which the cylinders and working parts are placed low down in the hull, in order to suit the

* See Tredgold, new edition, Division B, Marine Engines.

position of the screw shaft, and, in the case of the Royal Navy, to be protected from an enemy's shot. With this view, the cylinders of screw engines are often placed either horizontally or diagonally in the ship. As the screw propeller requires to revolve with considerable velocity, it is found necessary, in most instances, to increase the speed of the engines by gearing, so that the screw may make from two to three revolutions for each revolution of the engine crank. The use of toothed wheels on ship-board is not found, in practice, to be so objectionable as was at first supposed, an accident rarely happening to this part of the machinery when the wheels are properly proportioned as regards the strength of the teeth and the diameter. In order to counteract the jerking motion which would otherwise result, the teeth are arranged in steps (generally three in the breadth of the wheel), so that the opposing teeth are constantly in contact at one point at least, which causes the motion to be smooth and uniform, however great the resistance. Internal gearing has been successfully applied by Mr. Fairbairn for this purpose, the pinion on the screw shaft being driven by teeth on the internal periphery of the driving wheel. This gives a very smooth motion, as well as extra strength, from a greater number of teeth being in contact at the same time, and space is economized by the wheels lying one within the other. In the case of auxiliary steam power, or where a high rate of speed under steam alone is not aimed at, the engines are generally arranged to work the screw direct, without the intervention of multiplying gear, which should always be avoided when practicable. Speaking theoretically, there is no reason why a marine engine should not be driven at a much higher velocity than it is; but it is found in practice that a limit to the speed of the piston is imposed by the increased wear and tear of such complicated and expensive machinery, and its greater liability to get out of order. Hence the speed of the piston in screw engines working direct is rarely allowed to exceed 270 feet per minute. In these engines short and frequent strokes are required, as it is evident

that an engine with a three-feet stroke will give twice the number of revolutions of the screw that an engine with a six-feet stroke would give, the speed of the piston remaining the same in each case. When a large power is required, therefore, it is usual to combine three or four cylinders, working direct on the screw shaft, making short and quick strokes.

Screw-machinery in the Royal Navy.—So long as the paddle-wheel continued to be the propelling agent, it was plainly impossible to devise any means by which the machinery could be protected from an enemy's shot; but the adoption of the screw propeller has facilitated this very desirable object to the Navy. For as the screw itself revolves entirely beneath the surface of the water, we are now enabled to place all the machinery which gives it motion under the water line also, (in some cases, so much as six or eight feet,) by which means it gains a comparative if not perfect safety. It is well known that a shot will not penetrate more than a few feet under the water, unless it meet the surface at a high angle; but the bottom of a vessel at sea must be often exposed, during both the rolling and pitching motion, to a position considerably beneath the level water line, when an enemy's shot would have a fair mark at the machinery, although in smooth water it might be perfectly protected. The additional security, however, which such machinery *does* enjoy, renders it a question of the utmost importance to dispose the engines and boilers of a screw-propelled vessel in the Royal Navy, quite under the water line. Hence another reason for subdividing the power of large engines amongst a number of small cylinders, these being ranged (generally in a horizontal or inclined position) on either side of the screw shaft, so as to require as little height as possible for the reciprocation of their moving parts. The boilers are also made as low as practicable, and if a steam chest be added, provision should be made for shutting it off from the rest of the boiler in case of injury, the steam being in that case drawn directly from the top of the main boiler.

CHAPTER II.

DETAILS OF THE MARINE ENGINE: THEIR PROPORTIONS AND USES.

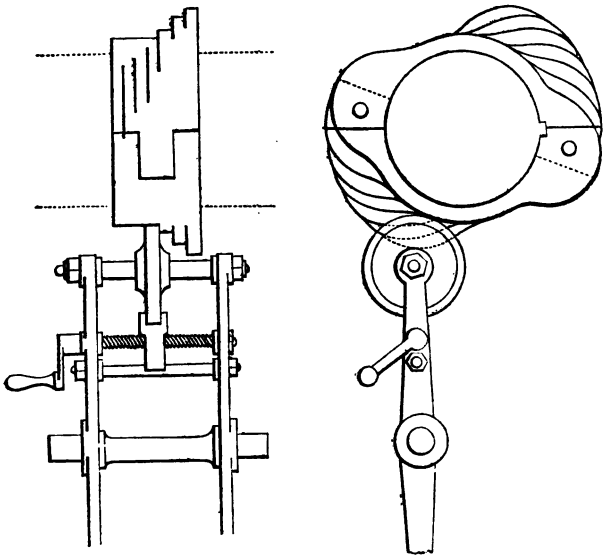
ALTHOUGH it is not here contemplated to supply rules and formulæ for proportioning the marine engine, a few remarks are made upon such proportions as the officer in charge of the engines may be able to alter or modify for himself if found necessary.

Steam Pipes.—The steam pipe from the boiler must not be too contracted, otherwise the pressure of the steam upon the piston moving in the cylinder is not kept up during its stroke, the steam being then what is called "wire-drawn" in the pipes. The usual area allowed to the steam pipe is one square inch per horse power, but this may be increased with advantage in the case of small engines. It is of much importance that the pipes should have as short and direct a route as possible from the boiler to the engines, with few angular bends or changes of direction, as all such impediments act most injuriously by checking the supply of the steam. Where bends are unavoidable, they should be made of as large a radius as convenient. Much care must also be taken to prevent the loss of heat by radiation, and the consequent condensation of steam in the pipes, which must therefore be clothed with sheets of hair-felt wrapped round with spun yarn, the whole being sewn up in canvas, and painted. Copper is the only material which should be used for steam pipes between the boiler and engine, as wrought-iron pipes generate scales of rust which, becoming detached, are blown by the steam into the valves and cylinder, where they do much mischief by scratching and cutting the surfaces. When a straight pipe

forms the connection with the boiler, an expansion or "fawcett" joint must be provided, but this may be dispensed with when an elbow occurs in the length of pipe.

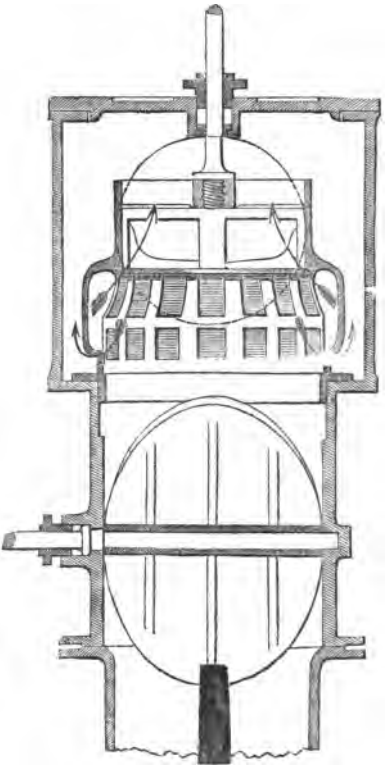
Throttle Valve.—The throttle valve of a marine engine is always worked by hand, and should be used only in controlling the speed of the engines for any temporary purpose, such as in passing through a crowded river, before stopping at a pier, etc., but should seldom or never be used for working the engines expansively at a permanent reduction of speed.

Expansion Valve.—This latter object is effected by the expansion valve, which should be fitted to all sea-going steamers.



It usually derives its motion from the crank shaft of the engine, the valve spindle being connected by a series of rods and levers with a small brass pulley which presses against the periphery of a graduated cam on the crank shaft, by which

means the steam is "cut off" in the most advantageous manner at any required portion of the stroke. The valve employed is usually of the description called the "Cornish double-beat," or equilibrium valve," which has the advantage of being opened and shut with great facility, since, from its construction, the



pressure of the steam has no tendency to jam it against its seat—the objection to which all flat or plate valves are subject. Also, by a slight rise of this valve, a very large opening is obtained for the steam. This will be best understood by reference to the annexed engraving. The principle on which this

valve is constructed is, that if steam be conducted by a branch pipe into a larger perpendicular pipe between two common conical valves placed in it, and connected together by a centre spindle or rod, and resting on their seats, it would exert a pressure on the under side of the upper valve, tending to raise it; and on the upper side of the lower one, tending to keep it down; these two pressures in opposite directions thus neutralizing each other. It is therefore evident that these two valves form one double-seated valve, and may be opened *in æquilibrio*, by means of their spindle. The steam then passes up one pipe and down the other, and, if desired, these pipes may be again immediately united. By the peculiar arrangement of the seats and partitions, this is done inside the outer casing of the valve, as shown in the engraving.

Stephenson's Link Motion applied to give Expansion.—A modification of Stephenson's elegant and simple link motion for locomotives has been adapted to the marine engine, by which means the length of stroke of the cylinder slide valves may be varied at pleasure, so as themselves to act also as expansion valves; but as their motion is derived from an eccentric of the usual form, it has a different character from that produced by the cam in the former instance; the admission and exclusion of the steam now taking place more gradually, and, as is generally admitted, with less effect.

To set the Slide Valves.—The manner of setting the cylinder slide valves so that they shall admit and shut out the steam from the cylinder at the proper time, independently of the action of the expansion valves, is a matter of the greatest importance. The chief points to be attended to are these: 1st, that the steam shall be shut off a little before the end of the stroke, by closing the aperture of the steam port, which causes the piston to be brought gradually to rest without jarring the engine, independently of the advantage derived from expanding the steam; 2nd, that the eduction port, or

the passage to the condenser, should be closed before the end of the stroke, which is termed "cushioning" the piston, because it then completes the stroke against an elastic *air-cushion*, in consequence of a portion of uncondensed vapour being shut up between the piston and the top or bottom of the cylinder; 3rd, that the steam port on the same side of the piston should be opened a very little before the end of the stroke, so that the steam may have acquired its full pressure as soon as the crank shall have turned the centre; and, 4th, that the communication with the condenser should also be opened on the opposite side of the piston a little before the end of the stroke, so as to have a vacuum ready made in the cylinder before the return stroke begins.

"*Lap*" *of the Valve*.—Now, if the slide valves had simply to admit and shut off the steam at each instant that the piston arrived at the top and bottom of its stroke, the face of the valve would have exactly the same depth as the aperture to be covered; but that the steam may be cut off a little before these points, it is necessary that the valve faces should be made deeper towards that side from which the steam comes, so that after closing the steam ports they may move past the aperture for a certain space at each end of the stroke. This space, which they *lap over* the valve seating, is called the "lap" or "cover" of the valve on the steam side. It is apparent that no lap is necessarily required on the exhaust side, because we want the communication with the condenser to *open* before the end of the stroke. The general practice on this point is, to make the edges of the valve faces flush with the edges of the cylinder ports, when the valves are placed exactly in the middle of their stroke. The objection to lap on the eduction side is, that the communication between the cylinder and the condenser will be closed too early, and the effect termed cushioning will take place to an injurious extent. The uncondensed vapour is compressed sometimes even to such an extent as to exceed in pressure the steam in the boiler, and an

erroneous opinion has then been formed in examining the lead corner of an indicator diagram, that the valve has been set to open too soon. In these cases, after due examination, the cover on the eduction side should be cut off. By means of the *lap*, therefore, we are enabled to shut out the steam, and to open the passage to the condenser before the end of the stroke. But it is also necessary that the port should open to steam on the opposite side before the commencement of the return stroke.

"Lead" of the Valve.—Steam is admitted to act upon the piston before it has quite completed its stroke, by giving the valve a motion in advance of the crank. The extent to which the port may be open for the admission of steam, when the engine is on its top or bottom centre, is varied much, but an allowance of one square inch of opening to every sixteen horses' nominal power, will be found to give good results. In all engines where the velocity of the piston is greater, the lead may be increased beyond this extent with advantage. With common slide valves driven by an eccentric great breadth of port is evidently desirable, as a slight motion of the valve then gives at once a greater area of opening.

Reversing the Engines.—If marine engines were required to work only in one direction, the eccentric pulley might then be permanently fixed on the paddle shaft (as it is on the fly shaft of a land engine), in the most advantageous position for *lead*, etc.; but as a steamer must be equally capable of reversing the motion of the wheels, such an arrangement becomes unsuitable. For let us suppose that the engine has been stopped at half stroke in the usual way, by throwing the eccentric out of gear and shutting off the steam, and that steam has been admitted by hand to the opposite side of the piston, the shaft will then commence revolving in the opposite direction. But it is evident that before the engine can be thus put into the proper position for enabling the eccentric to

continue the reversing motion, the shaft must be free to rotate *backwards* within the eccentric pulley through half a revolution. Hence a necessity arises for placing the eccentric pulley loose upon the paddle shaft, the latter being fitted with a "stop" or "snug" with which another "stop" cast on the pulley comes into contact after half a revolution in either direction, and thus communicates motion to the valves with perfect indifference as to which end of the eccentric stop may be in contact.

Expanding by Means of the Lap on the Slide Valves.—It is apparent that the lap of the slide valve presents a simple method of working the steam expansively to a small though definite extent, which is then fixed beyond the power of alteration until the valves are reset. The amount of expansion which can be thus given, is limited by the effect produced upon the eduction port as before mentioned. It is, however, objectionable to carry expansion by this means to the full extent to which it is practicable, from the fact that when the vessel is placed in the most difficult circumstances, struggling off a lee shore, with the speed of her engines reduced by a head wind, so that there is an abundant supply of steam, there are then no means of completely filling the cylinders, and the full amount of power capable of being generated cannot be realized. The most beneficial practice therefore, when the common slide valves are used, is to have only a small amount of lap, so that it may be possible to obtain the utmost power that the engines are capable of exerting at such times as it may be essential, and to have an additional valve for regulating the amount of expansion to such extent as may be desired. The latter system is in accordance with the growing intelligence of those now generally entrusted with the working of marine steam engines. An excessive and wasteful expenditure of steam under circumstances when a corresponding result cannot be obtained from it need not be feared with a good superintending engineer on board, as so much interest has

of late been excited not only amongst those parties, but also amongst commanding officers, on this most important point.

Blow-through Valve.—Before the engines can be started it is necessary that the air should first be expelled from the cylinder, condenser, and air-pump, and its place supplied by steam, in order that we may obtain a vacuum by its subsequent condensation. Hence a valve, called from its office the "Blow-through valve," is provided to open a temporary communication between the steam in the valve casing and the condenser, by which means a rush of steam is caused to pass through the internal parts of the engine. This operation is continued until the steam begins to issue, hot and transparent, from another valve on the condenser, called the "Snifting valve," situated at the opposite point from where the steam entered. These valves are of course closed as soon as the engine is set to work.

Clothing the Cylinders, etc.—As it is of much importance that the internal heat of the cylinders and valve casings should be preserved from radiation (especially when high steam is used expansively) these must be carefully clothed with felt and dry timber, bound round with metal hoops.

Clearance of the Piston.—The "clearance" of the piston at the top and bottom of the stroke should be just as little as is consistent with safety, and is usually made from a half-inch to five-eighths or three-fourths of an inch.

Priming Valves.—"Escape" or "Priming valves" are now generally fitted to the top and bottom of the cylinder, to permit the escape of water without danger to the machinery from the shock of the piston against the incompressible fluid. This water collects partly from the condensation of steam within the cylinder, but is chiefly carried over from the boiler, either as "priming," or in a state of mechanical sus-

pension with the steam. It may also overflow through the valves from the condenser. These valves should be fitted with hoods to carry off the ejected water into the bilge, and prevent its being thrown about the engine room.

Packing for the Piston.—Metallic packing is now universally employed for the pistons of marine engines, this being made in the form of cast-iron rings, either possessed (from their construction) of elasticity in themselves, or deriving it from steel springs placed behind them. The cast-iron rings, unfortunately, lose their elasticity after being some time in use, in which case they must be taken out, and have this restored by hammering and thereby elongating their internal surface; or else steel springs must be added to press them out against the cylinder, when they are cut into segments to allow the springs greater freedom of action. The piston is lubricated with melted tallow through a grease-cock on the cylinder cover, advantage being taken of the vacuum during the up-stroke to suck in the tallow. The grease-cock aperture also serves for applying the "Indicator" during the stroke above the piston.

Condenser.—The condenser should have a capacity of half the cylinder as a *minimum*, but may be made larger with advantage. The size should depend, to a certain extent, upon the temperature or density of the steam used, as plenty of room should be allowed for high steam to expand into low-pressure steam before being condensed, if this has not been previously effected by expansion within the cylinder.

Injection Valve.—The area of the injection valve should be about one square inch for every ten-horse power. This is an ample allowance in all cases, and is more than necessary when the injection water has a temperature of 52° Fahr. (which is the average for our seas), though in tropical climates it will not be found too much. The average tempe-

rature of the Mediterranean is about 65°; at 20° of latitude, about 75°: and at the equator, about 82°, Fahrenheit. The supply may be regulated at will by the opening given to the valve, as shown on an index plate. It is better in the case of large engines to have two injection cocks fitted between the sea and each condenser,—one, the *sea cock*, close to the side of the vessel, as a security in case of injury to the internal pipe, and the other upon the condenser. Besides these, it is usual to have an injection pipe led from the bilge of the vessel, so that in case of unusual leakage the sea cock may be closed, and the engine supplied with injection from this source. The mouth of this pipe should be carefully guarded and kept clean, as when the emergency arrives for its use it has too often been found choked up and unserviceable.

Temperature of the Condenser.—The process of condensation will be the more complete in proportion to the coldness and quantity of the injection water, the manner in which it is brought into contact with the steam, and the temperature of the steam itself on entering the condenser. The resulting temperature which is usually aimed at by engineers for the condenser is from 90° to 110°. The limit to a more perfect degree of condensation is imposed by the increased size of the air pump required to withdraw the additional injection water, which diminishes the work and increases the cost of the engine. Hence the engineer is well satisfied if the temperature of the condenser be not above 110°, with which a vacuum of 27½ or 28 inches of mercury is obtained by a good engine.

Elasticity of Watery Vapour at different Temperatures.—According to Dr. Ure's experiments, uncondensed watery vapour at a temperature of 100° balances 1·86 inch of mercury; at 110°, 2·45 inches; at 120°, 3·3 inches; at 130°, 4·366 inches; at 140°, 5·77 inches; and at 150°, 7·53 inches of mercury, or exerts a pressure of 3¼ pounds per square inch.

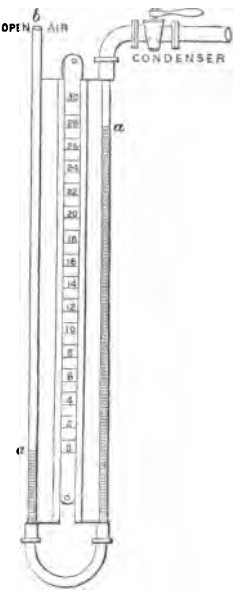
Flow of the Injection Water.—The velocity at which injection water enters the condenser varies as the square root of the pressure, and will be about 40 feet per second for the full pressure of the atmosphere against a pure vacuum. The sea injection should be taken from about midway between the surface of the water and the bottom of the vessel, so as neither to draw impurities from the surface, nor be liable to become choked with sand or mud from the bottom, when working in shallow water, or when the vessel is aground. In many of the latter cases, the engines have been rendered useless at the time when most needed, by sand being sucked in and destroying the action of the air pump.

Barometer Gauge.—A barometer gauge is attached to the condenser to show the vacuum. It is usually constructed like a common barometer, except that the top of the glass tube communicates through a small pipe and cock with the interior of the condenser, the partial vacuum of which then takes the place of the Torricellian vacuum of the ordinary barometer. The surface of the column of mercury in this case indicates the difference which exists between the pressure of the atmosphere and the pressure in the condenser, so that if we see a column of 27 inches of mercury supported in the tube, and the pressure of the atmosphere at that time be 30 inches of mercury, we know that there is a pressure of three inches of mercury, or $1\frac{1}{2}$ lb. on the square inch within the condenser.

Sources of Error.—As we find by the common barometer that the pressure of the atmosphere is constantly varying, a correction should be made for this in estimating the vacuum of the condenser. Another source of error arises from the varying level of the mercury in the open cup which supplies the gauge tube, according as the tube becomes more or less filled; since it is evident that only that portion of the column which rises above the surface of the

mercury in the cup can be reckoned as the counterpoise to the atmosphere. The simplest manner of *alleviating* the last-mentioned source of error is to make the surface of mercury in the cup very large in comparison with the bore of the tube. As the barometer gauge is very often found to show incorrect results (either through ignorance or design on the part of the foreman who saw it fitted), it would be well if every commander of a steam vessel satisfied himself of its accuracy, before giving credence to such wonders about vacuum as are sometimes published to the world.

Improved Barometer for the Condenser.—Subjoined is a sketch of an improved barometer for the condenser, which has been tried and found useful. A glass siphon tube, *a a*, 34 or 35 inches long, is half filled with mercury; one end, at *b*, being left open to the atmosphere, which is admitted through a very small aperture, to exclude the dust. A sliding brass scale, graduated from 0 at the bottom to 30 inches at the top, is fitted in the space between the two legs of the inverted siphon. When required to show the vacuum, the zero point of the scale must be shifted to where the mercury falls in the leg open to the atmosphere, and the height of the mercury in the other leg being then read off from the scale, the exact difference of height between the two columns is thus obtained. This barometer possesses also the advantage that the mercury cannot be blown out by a slight pressure of steam in the condenser (as is the case with the common barometer), which admits of its being kept in



constant use as a guide to the engineers in stopping and starting their engines in any time of difficulty. The siphon may be made, if preferred, by uniting two straight glass tubes in a short piece of bent iron pipe.

Evils arising from the Use of Sea Water for Condensation.—The use of sea water for condensing the steam and subsequently feeding the boilers, entails upon marine engines the necessity for ejecting, or "blowing off" a portion of the saturated water, at intervals, into the sea, to prevent the deposition of scale and salt, and causes the loss of a considerable quantity of caloric. The specific gravity of the salt water in the boiler, taken at a medium degree of saturation, is about one-tenth part greater than that of fresh water; and as the capacity of the water spaces requires to be increased to allow for cleaning as well as for the more ready escape of the steam through the denser fluid, we may add about one-fifth for the extra weight of salt water in the boiler as compared with fresh, taking into account the portion which is blown off. When we consider also the very rapid wear of boilers using salt water, it is at once apparent that an efficient means of supplying them with fresh water at sea is one of the greatest desiderata in marine engineering.

Surface Condensation attempted.—With this view, many attempts have been made to condense the steam by contact with cold metallic surfaces, instead of by the plan of injecting amongst it a large body of salt water from the sea. Could this be done effectively, the boiler might then be fed, during the whole voyage, with the fresh water which it had at starting; the same water, after circulating through the cylinder as steam, being condensed without intermixture with other water in the condenser, and then returned to the boiler to be again formed into steam, being thus kept in a continuous round of action.

Surface Condensation found to be Inefficient.—But, unfor-

tunately, the principle of surface condensation has hitherto always proved inefficient. The difficulty has been to present a sufficiently large cooling surface to the steam, so as to produce as rapid a condensation as is obtained by the plan of injecting cold water amongst it. In Hall's Condensers, the steam was passed through many miles of little copper pipes enclosed in a cistern of cold water, which was constantly renewed from the sea by means of a force pump worked by the engine; but in this case the small pipes through which the steam was passed were found liable to become "furred" on the outside, or choked up altogether by deposits from the sea water. Besides this, the additional machinery required added so much to the expense and intricacy of the engine, as well as to its weight and the space it occupied in the vessel, that this condensing apparatus has not been found applicable in practice. In such an arrangement the loss of steam arising from leakage, or from blowing off at the valves, is compensated to the boiler by the use of a small apparatus for distilling sea water. The air pump is then, of course, much reduced in size, as it has no injection water to remove.

Air Pump.—The capacity of the air pump is usually proportioned to the cylinder as 1 : 8, or thereabouts; and the delivery valve has an area of one-third of the air pump, though the orifice through the ship side for the escape of water from the hot well need not be more than one-sixth of the area of the air pump, when the latter is single-acting. In large engines, a sluice valve is usually fitted inside the vessel across the mouth of the discharge pipe at the ship side, which, being closed by hand when the engines are not working, prevents the wash of the sea from entering the hot well, as well as acting as a safeguard to the ship in case of breakage of the internal pipe.

Feed Pumps.—The feed pumps supply to the boiler so much of the water which has been used in condensing the

steam as will restore the waste from evaporation and blowing off, and each of the two feed pumps which are usually fitted up is made sufficiently large to supply all the boilers in case of accident to the other pump, or to its feed pipes. The necessary quantity to be admitted to the boiler is judged of by observing the level in the glass water gauge, and is regulated by hand by means of the feed cock on each boiler—the surplus water, which is rejected by the boiler, being expelled into the sea by the feed pump through a loaded escape valve.

Bilge Pumps.—Bilge pumps are fitted to marine engines as a security to the ship in case of extraordinary leakage, as well as to save the work of the crew in pumping the hold dry. The bilge pipes should be made of lead, which suffers less corrosion than copper from the acidulous bilge water of wooden ships, and care must be taken that they do not get choked with filth.

Hand Pump connected with the Engines.—A hand pump must also be fitted for the purpose of feeding the boilers while the engines are at rest and the steam blowing off. This is made capable of being connected to and driven by the engines, so as either to assist in feeding the boilers, if necessary, to act as a fire engine in case of need, or for the every-day duty of washing decks. It should also be so arranged that it may draw either from the sea or the bilge.

Feed Pump driven by a Supplementary Engine.—In the case of vessels with tubular boilers, this pump receives its motion from a small high-pressure engine (technically known as "the donkey") which works by the pressure of steam in the large boilers. Such a provision becomes necessary on account of the rapid evaporation of tubular boilers in comparison with their confined area at the water level; but in the case of flue boilers, where the water surface is comparatively

larger, and danger from the water level falling too low during a temporary stoppage is therefore diminished, the feed pump is generally worked by hand only. The "donkey" is also made to do duty as a fire engine, drawing water either from the sea or the bilge.

CHAPTER III.

THE MARINE BOILER: ITS GENERAL PROPORTIONS, AND THE PRINCIPLES CONCERNED IN ITS OPERATION.

The Marine Boiler.—The Marine Boiler differs from one on shore in this essential particular, that, in the former, the fire and flues are wholly contained within the boiler itself, and are surrounded with water in every direction,—such an arrangement being rendered necessary as a precaution against fire. There are several varieties of this boiler in use, designated the Rectangular flue boiler, the Tubular boiler, the Sheet-flue boiler, &c.

Flue Boiler.—In the Rectangular flue boiler, the flame and hot gases generated in the furnace are confined in narrow flues, which wind about amongst the water of the boiler until the heat of their contents has been nearly all absorbed; after which, the flues are gathered together into the "up-take," at the bottom of the chimney.

Form of the Flues.—They should be so roomy as to allow of a boy getting readily through them to clean out any deposit of soot or ashes; but their area must not be unduly increased in any one place, so as to check the velocity of the draft, as in that case a deposition of soot and ashes invariably takes place, by which the heating surface is not only impaired, but the plates are corroded and destroyed.

Arrangement of the Heating Surface.—It is a point of the utmost importance that no part of the heating surface of a boiler should be so situated that the steam may not readily rise from it and escape to the surface of the water; since the

plate, if left in contact with steam instead of water, becomes unduly heated and destroyed, and an explosion frequently ensues.

Horizontal Heating Surface the best.—It is found in practice that a perpendicular heating surface, such as the sides of rectangular flues, is by no means so efficient for raising steam as an equal area of horizontal surface, such as the tops of the same flues or of the furnaces. The reason of this is sufficiently apparent; for the steam in the first case, rising perpendicularly from every portion of the surface, forms a film or stratum of vapour in contact with the sides of the flue, which prevents the free access of the water to the hot metal; but, in the other case, the steam leaves the iron as soon as it is generated, and allows the water to be constantly in contact.

Bottom Heating Surface inefficient.—From the same cause of imperfect contact, the flat bottom of a metal flue is very inefficient as heating surface; and plates thus disposed are found to wear out much quicker than those forming the tops of flues or fire boxes. The plan of covering the bottom of the flues with a non-conducting material, as bricks or cement, has been found to cause hardly any diminution in the evaporative power of the boiler, and is by some thought to increase the durability of the bottom plates.

The objection to this plan is, that from the unequal degrees of expansion between the iron and the non-conducting lining, it is impossible to maintain an unbroken joint between their surfaces, so that a space is formed in which brine may collect in contact with the plates, and thus do more mischief than the original disease.

The flues generally increase a little in height as they recede from the furnaces, in order that the depth of water over them may be less in proportion as the contained air is cooler.

Disadvantages of Flue Boilers.—Although flue boilers oc-

cupy at least one-third more space in the vessel than tubular boilers of an equal evaporative power, and are nearly one-third heavier, they are still preferred in some instances (as on board the West India mail packets), as being more economical both with regard to first cost, repairs, and durability. It is hardly believed, however, that these qualities, if really possessed, are not more than counterbalanced by the increased consumption of fuel necessarily attending any increase in the displacement of the vessel, as well as in the loss of so much valuable space for passengers, goods, or stores.

Tubular Boilers.—In tubular marine boilers, the flame and hot gases from the furnaces are led through a great number of small tubes (of iron or brass), completely surrounded with water, to the flue or "up-take" at the bottom of the chimney. By this arrangement we are enabled to condense a very large amount of "heating surface" within a comparatively small space; and in consequence of the extreme subdivision of the heated gases in passing through several hundreds of tubes not above three inches in diameter, every particle of them is brought into contact with the absorbent surface, and their caloric is thus abstracted in the smallest possible time.

There is much difference of opinion as to whether iron or brass tubes are preferable, for although the first cost of iron tubes is much less, the brass tubes generally last twice as long, and they certainly give more steam by conducting the heat more rapidly to the water. On the other hand, it is difficult to keep brass tubes so tight as iron ones, in consequence of the different degrees of expansion of brass and iron by heat. With regard to the durability of brass tubes, much depends upon the hardness of the alloy (copper and zinc) of which they are made, instances occurring of a very rapid wear from the metal being worn away by the passage of the cinders and ashes through them.

Sheet-flue Boilers.—The best specimen of this description

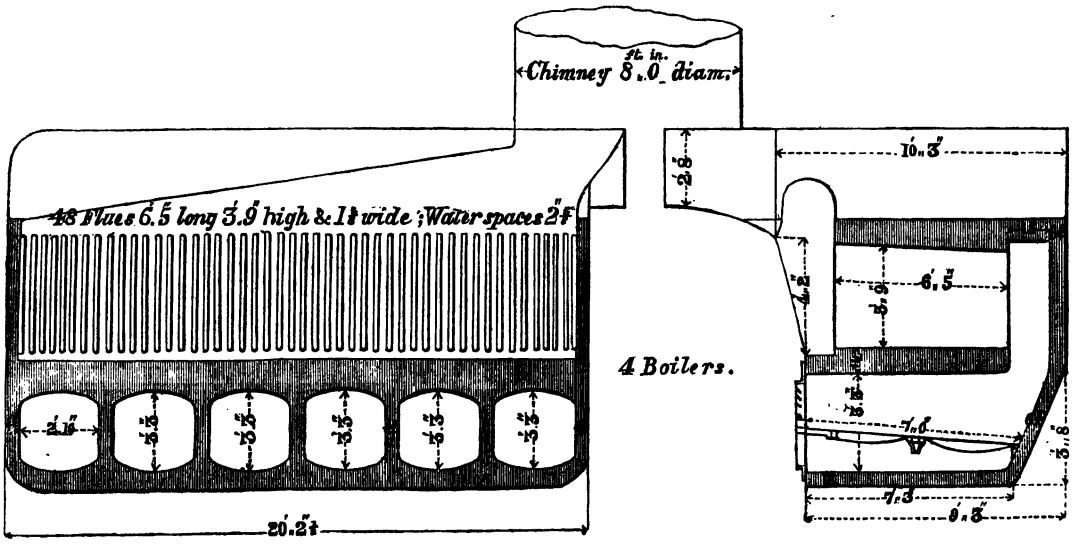
of boiler is that patented by Messrs. Lamb and Summers of Southampton, and extensively used in the service of the Peninsular and Oriental Steam Navigation Company, where they give much satisfaction. A drawing of those fitted in the *Himalaya*, Government troop-ship, is given on the next page (p. 40). They appear to possess some advantages over the tubular boiler, the surfaces in contact with water being more easily kept clean and free of deposit, the joints requiring but little attention to keep them tight and in good repair, and their flues are certainly more durable than either brass or iron tubes. They are somewhat heavier than tubular boilers of the same size, and although they may not give so much steam as boilers with clean brass tubes, their average performance appears to be nearly equal to that of most tubular boilers. We have seen the flues of these boilers after six years' service as sound, apparently, as when they were first made, and without having undergone any repair during that period.

Furnaces.—The furnaces, or "fire boxes," should be so deep as to allow of a roomy ash-pit under the doors, the front of the grate bars being fixed at a height of about thirty inches above the firing stage, and sloping down with an inclination of about two inches to the foot towards the "bridge."

Fire Bars.—Cast-iron bars are now usually preferred to wrought iron, the latter being so liable to soften and get out of shape with the heat. They should be made not more than 2½ to 3 feet long, generally two lengths to the furnace, which itself should not exceed 6½ or 7 feet, this being the utmost length that can be conveniently managed by the firemen. The bars should be ¾ in. or ⅞ in. thick on the upper edge, between 3 and 4 inches deep in the middle, and with an air-space of ⅜ in. to $\frac{7}{16}$ in. between them for Welsh coal, though this space should be modified according to the fuel intended to be burnt, so that neither too many cinders may fall through, by the spaces being too wide, nor the fires smo-

LAMB AND SUMMERS' PATENT SHEET-FLUE BOILERS

In H. M. Steam Troop-ship Himalaya.



thered for want of air. No open space should be left between the outer bars and the sides of the furnace, as it is better to check the draught at that part, to prevent the formation of flame, and keep the plates from being "burnt."

Chanter's Patent Fire Bars.—An arrangement known as "Chanter's Patent Movable Fire Bars," has been successfully tried in several steamers, and appears worthy of more extended use. The bars are cast with teeth on the upper edge, thus; and are so arranged on the bearers, that the *alternate* bars are capable of being moved a distance of about 2 inches backwards and forwards, by means of a short lever worked by the firemen, the intermediate bars remaining fixed. The great advantage of this is, that by the movement of the alternate bars a tearing and grinding action takes place, which thoroughly breaks up the clinkers, and the coal, if it is disposed to cake, and cleans the interstices between the bars without the "slice" or any other tool being required. A regular supply of air is thus maintained, which preserves the bars themselves from being burnt, and gives a clear, open fire, with comparatively small labour to the firemen.

The direct Impact of Flame to be avoided.—It should be borne in mind that the direct impact of flame is very much hotter than radiant heat, and the plates of a boiler should be protected from it as much as possible. This forms a source of objection to many of the plans which have been proposed, or adopted, for burning the inflammable gases in the flues of a marine boiler by the admission of a jet of air, which too often acts like a blow-pipe by directing the flames thus generated against the plates.

The Bridge.—The "Bridge," to which we have alluded, crosses the back of the furnace to support the ends of the

fire-bars, and prevent the fuel being carried into the flues. It also causes the flame to reverberate upon the roof of the furnace, although some boilers, from their construction, do not require it at all. It is either formed of fire-brick, or else constitutes a part of the boiler by being made hollow, and containing water, in which case the top of the bridge inclines at a considerable angle, to allow the escape of steam, without which precaution it would be speedily injured by the heat.

Water Spaces.—The furnaces should be covered with fourteen or fifteen inches of water, and the tubes or flues with ten or twelve inches, in the case of sea-going steamers. The water spaces between the furnaces are usually five to six inches wide; and between the flues, four to five inches. The spaces between the crowns of the furnaces and the bottoms of the tubes should be not less than ten inches, to allow of a "man-hole" between the arched tops. The bottom water spaces should be not less than eight inches, to allow room for "scaling" and cleaning. It is usual to allow a space of one inch between the tubes of a tubular boiler, these being arranged in perpendicular rows, one over the other, by which means the steam is supposed to escape more readily than when they are placed *zigzag*.

Nothing so much affects the duration of a boiler as the greater or less accessibility of every part in contact with water, for wherever the plates cannot be conveniently reached for cleaning or scaling, a deposit is sure to collect at that place, and the plates to get burnt and weakened in consequence. It should always be borne in mind that in such cases the actual cost of the repair is but a small part of the loss entailed upon the proprietors of steamers, the principal loss arising from the detention of the vessel while the repairs are being made.

Although many of the proportions here set down are beyond the control of the officers in charge of a steam vessel, still we think it expedient to state, in as few words as possible, what proportions of engine and boiler are considered by

practical men to be most conducive to perfect efficiency. For unless a general knowledge of these proportions be acquired, it is plainly impossible to form a judgment as to whether any observed deficiency in the work of the engines is due to the fault of their original construction, or depends upon those details of *management* which it is more particularly our present object to explain. And although it is but just to the talented constructing engineers of this country to assume, that in the majority of cases the machinery of a steam vessel leaves their hands in a perfect state, it is nevertheless most satisfactory to be enabled to prove this for one's self.

Requisite Amount of Heating Surface.—Before we can obtain a good average result from the combustion of the fuel, it is necessary that the boiler should present about twelve square feet of effective heating surface per horse power; for if less surface than this be given, a wasteful quantity of heat escapes up the chimney, from not having been absorbed by the water. What is termed "effective" heating surface, must be calculated independently of the bottoms of flues and fire boxes, and of one fourth part of the whole tube surface. The grate bar surface should be *at least* eighty square inches per horse-power, and, where practicable, may be increased to one hundred square inches with much advantage.

The temperature of the air at the bottom of the chimney is, to a certain extent, a test of the sufficiency of the heating surface; but as this depends also upon the rapidity of the draught through the tubes or flues, as well as upon the degree of cleanness of the surfaces of the metal, it is not always a sure test. The degree of heat found at the bottom of the chimney appears to vary in different boilers from 400° to 700° Fahr.

Areas of Flues and Tubes.—The area of the first flue, or the clear area through the tubes, should equal one-sixth of the grate bar surface led into them; and the area of the flues

may be gradually diminished from the fires to the chimney by one-fourth part.

A Roomy Furnace desirable.—As a large furnace is found by experience greatly to facilitate the admixture of the gases, and to ensure their more perfect combustion, as well as to afford the most effective kind of heating surface, it is of great importance that there should be plenty of room over the fires.

Combustion checked by the Carbonic Acid.—The carbonic acid gas which results from the combustion of solid carbon, has a most injurious effect in checking combustion within the furnace, for we find by experiment that flame is barely supported in a mixture of one part of this gas with four of atmospheric air. Hence the necessity for admitting into the furnace at least twice the amount of air chemically required; and even then, if we analyze the contents of the chimney, we shall find from one-fourth to one-half of the oxygen which entered the fire still free and uncombined, mixed up with the products of combustion.

Supply of Air to the Fires.—The amount of air that is required to keep up combustion in steam-engine boilers is much greater than is usually supposed. For 1lb. of coal, of average quality, 150 cubic feet of air are required for exact chemical combination alone, and as this can never be perfect, from a variety of disturbing causes, a supply of about 300 cubic feet is found in practice to be beneficial. If 8lbs. of coal be consumed for one horse-power per hour, an engine of 100-horse power will require a supply of 2400 cubic feet of air per hour, or 40 cubic feet per minute. Every facility therefore, by means of hatchways, wind pipes and windsails, should be provided and carefully attended to for this large supply.

Loss of Heat attending the Combustion of the Inflammable Gases.—Now, as the whole of the air thus supplied in excess

must be heated to a very high temperature before the combustion of the inflammable gases in the furnace can ensue, much heat is thus unavoidably wasted,—so much, indeed, that it is now well ascertained that the evaporative value of a bituminous coal producing a large quantity of gaseous matter is very little, if at all, superior to the evaporative value of the same coal *after being coked;* the heat generated by the combustion of its volatile products proving, in practice, to be little more than that expended in volatilizing them, and in heating the surplus air required for their subsequent combustion.

Formation of Carbonic Oxide.—When a stinted supply of oxygen is furnished to the incandescent fuel on the bars, an imperfectly oxygenated carbonic acid gas, named "carbonic oxide," is partly produced, accompanied by a corresponding loss in the heat generated during combustion. As this gas is inflammable, and that at a comparatively low temperature, it may be burnt in the furnace or flues, by the admission of a further supply of atmospheric air; otherwise it escapes unconsumed up the chimney, where it may be often seen burning at the top, having caught fire upon coming into contact with the oxygen of the air. Although it may be beneficial to consume this carbonic oxide, when once formed, by admitting fresh air into the flues behind the bridge, it is certainly preferable to prevent its formation altogether, by using a large grate surface, a thin fire, with plenty of air-space between the bars, and a roomy furnace.

Smoke-burning Apparatus.—Notwithstanding all that has been done and written with reference to the so-called "smoke-burning" apparatus, it is the opinion of those most capable of forming a correct judgment on this subject, that by a proper construction of the furnace, and a skilful management of the fire, the smoke and gases may be as effectually, and certainly more safely, consumed by admitting the requisite quantity of air for this purpose at once through the grate bars.

Recapitulation.—It may be gathered from the preceding remarks, that some of the most important requisites to ensure efficiency in a steam boiler are the following:—1st. That the boiler should be designed with a sufficient amount of heating surface, so contrived that as little of it as possible may be rendered ineffective, either from the retention of steam in contact with it, from the formation of scale within, or from the deposition of soot and ashes in the bottoms of the flues and tubes. 2nd. That the fire-bar surface should be sufficiently large to admit of the necessary quantity of coal being consumed with thin and open fires. 3rd. That the proper area be maintained through the flues or tubes, and that the passage to the chimney be such that the draft may not be interrupted. 4th. That the furnace should be roomy; the bars thin, with plenty of air-space between them; and that the fires should not be longer than can be conveniently stoked. And, 5th (which is, perhaps, the most important requisite of all, and the one most neglected), That experienced and careful fire-men be provided.

Clothing Marine Boilers, found to be sometimes prejudicial.—Although it must be admitted that the practice of "clothing" marine boilers with non-conducting materials, such as hair-felt, wood, etc., is in all cases highly beneficial for the production of steam; yet this is alleged to have induced, in some instances, a rapid wear in the plates of the boiler. This corrosion is most apparent in boilers which are frequently used and disused alternately, and takes place on the interior surface, attacking principally the top of the boiler and the steam chest. It is probably owing to the alternate wetting and drying of the plates, which causes the rust to scale off, and thus present a fresh surface for corrosion each time that the water is blown out of the boiler. In the case of an unclothed boiler, on the other hand, the internal surface is scarcely ever quite dry, from the evaporation being checked by the low temperature and the consequent saturation of the enclosed air. Marine boilers which are constantly in use, or which make long voyages only,

do not experience this destructive corrosion of the steam chests to the same extent.

Painting the Inside of the Boiler.—It is an excellent practice to paint with red lead all the inside of the boiler which is exposed to steam, as a preventive of corrosion. The tops of the boilers should always be carefully preserved by a covering of sheet-lead, or otherwise, from water dripping on them from the decks, else a rapid corrosion will take place there.

Bedding Marine Boilers.—The manner of bedding boilers is a point of some importance, as it materially affects the duration of the bottom plates. The method formerly employed was to lay them on a close platform of wood, with the view, chiefly, of preventing the bilge water (which in wooden ships is highly acid) from washing up to and corroding the plates. It was found, however, that if a leak occurred in the bottom of the boiler, the brine diffused itself for a large space between the bottom plates and the wooden platform, causing great corrosion. The usual practice now is to rest the boilers upon iron keelsons, the bottom being thus left comparatively open for examination and painting, and for small repairs if wanted. In this case, the bilges under the boilers must be kept quite clean and dry by the bilge pumps.

Galvanic Action.—It is necessary, both in marine engines and boilers, to guard against the destructive effects of galvanic action, which ensue in all cases where two metals of different degrees of solubility (or possessing different degrees of affinity for oxygen) are placed in juxtaposition; as, for instance, iron and brass, when the former metal suffers a rapid corrosion from being the more oxidizable of the two, while the brass is quite protected.

Copper Boilers.—In cases where the frequent renewal of boilers is attended with great expense and inconvenience, they

are sometimes made of copper, which lasts about four times as long as iron. Their first cost, however, is about five times greater for boilers of the same weight, and copper is only three-fifths of the strength of iron when cold, or less than half its strength at 500° Fahrenheit. Iron, on the contrary, increases in strength from 32° to 550°, when its strength is believed to be at a *maximum*. It is evident, however, that although a copper boiler is not so strong as a *new* iron one of the same weight, it retains its original strength unimpaired for a long time, whilst the iron boiler is every day becoming weaker by corrosion. An iron boiler, when new, has thus a great superabundance of strength, to allow for the wearing of the plates by use; and it must on no account be forgotten, that a boiler which may show no symptoms of weakness on being first used under a pressure of 20 pounds on the square inch, may be very unfit to work at this pressure after a couple of years' service. As copper conducts heat more readily than iron, in the ratio of 2·4 : 1, a copper boiler does not require so much heating surface as an iron one. Also, after the copper boiler is worn out, the old material is still valuable, whereas the price obtained for the scrap iron is little more than what it costs to break up an old iron boiler.

Staying Boilers.—It is usual to stay the flat portions of tubular boilers with rods from an inch to an inch and a half in diameter, from sixteen to eighteen inches apart each way, and flue boilers (which are not so well adapted to bear a high pressure of steam as tubular boilers) not quite so heavily. It must be borne in mind, that it is highly injurious to stay weak plates at long distances, however strong the stay rod may be, as the alternate distension and contraction of the plate between the stays causes it to *buckle* round each stay every time that the pressure of steam is added or removed. This action in time wears a furrow round the fastening of the stay, by throwing off the scale from the surface of the plate, and opening the fibre of the iron.

CHAPTER IV.

THE MARINE BOILER: MANAGEMENT OF THE FIRES AND DRAUGHT.

The skilful Management of the Machinery necessary for its Efficiency.—Having endeavoured to show in as few words as possible what the machinery of a steam vessel is, we proceed to consider, in the next place, how it may best be used: for, notwithstanding all the talent and perfection of workmanship which may be displayed by the constructor, it still rests mainly with those to whose care it has been entrusted, whether this costly machinery shall give satisfaction or not.

Economy of Steam is the main Question.—The economical working of an engine evidently depends upon the quantity of steam which is required to do a given quantity of work, so that the whole question resolves itself into this, how can we best save steam? This question, again, naturally divides itself into two heads, which are really quite distinct, though too often associated together; namely, the production of steam in the boiler, and its subsequent use in the engine; and we shall therefore consider those separately.

The Generation of Heat in the Furnaces.—The economy of a steam boiler is subdivided into the *generation* of heat by the combustion of the fuel in the furnace, and the subsequent *absorption* of this heat by the water, as has been already commented upon. As the latter is beyond the control of those in charge of the machinery (except in keeping the surface of the flues and tubes as clean as possible), we shall not further advert to it, but will proceed to the management of the furnace.

Management of the Fires.—The management of the fires on board a steam vessel affects the question of economy in the consumption of coal to so great an extent, that the importance of skilful firemen cannot be too much insisted upon. It is a great mistake to suppose, as too many captains and owners of steam vessels do, that any able-bodied man who can throw coals on a fire is fit for a stoker: and under this false impression, *sailors* are frequently engaged, instead of regular firemen, "to stoke when required." The only cases in which this should be allowed are, perhaps, in auxiliary-screw vessels, and in such vessels as may be expected to make a considerable portion of their voyage under canvas; but even in such cases there should always be one well-trained fireman for each watch, to have the charge of the other stokers. This man should be kept constantly at his post, and must not be liable to be called away while the vessel is under steam, except in cases of emergency; and he should receive a higher rate of pay than the other stokers, if it were only for the purpose of giving him the necessary authority over them.

Effects of Mismanagement.—Thus, many instances of steamers are to be found at the present day in which the same quantity of coal is regularly burnt per hour, whether the engines are going fast or slow; whether forty cylinders full of steam are used per minute, or only thirty. In such a case, one quarter of the fuel is thrown away through ignorance of the despised art of stoking; for the firemen may have either allowed the surplus steam generated to blow off at the waste-steam pipe; or they may have thrown open the fire doors, by which means the steam is only prevented from being generated by the rush of cold air which takes place through the flues, while the same quantity of coal is burnt as before.

Feeding the Furnaces.—Boilers of the proportions most usually adopted by constructing engineers are suited for the

combustion of from fifteen to eighteen pounds of coal upon each foot of grate surface per hour. In applying this fuel, it is found most advantageous to throw on at one time a supply to last for about twelve minutes, the furnace door being opened in about eight minutes after the fire has been fed, to see how the coal is burning; and if any part of the grate has burnt bare, a little coal must then be quickly and skilfully thrown over that place; or should the coal appear to lie too thickly at any part, it must be levelled with the "rake."

Clearing the Bars.—In the case of a very bituminous coal it is often found necessary to open or break up the fire at this time, owing to the tendency of such a coal to cake on the bars, and thus prevent the passage of air through them; but this may be obviated to a certain extent by keeping the fires thinner with bituminous coal than would otherwise be desirable.

Keeping the Fire Doors shut.—As it is of the utmost importance that the fire door should not be open longer than necessary, since the cold air which then rushes in acts most injuriously by absorbing heat from the flues, the experienced fireman will study to dress his fire, in the first instance, so as to demand as little interference as possible between the times for throwing on fresh fuel, or "firing-up," as it is termed.

Levelling the Fuel.—The fires should be kept of a moderate and equal thickness throughout, and as the firemen are very apt to heap up coals at the far end of the bars, it is a good practice to make each set of men, before leaving their watch, lay the rake or pricker along the surface of each fire quite back to the end of the furnace, in order to find whether the thickness of the fuel is uniform or not. Should any of the fires then want dressing, the firemen under whose charge they are should be forced to remain until those fires have been brought to a regular and proper thickness.

Each Watch to leave their Fires clean.—It is the general practice for each set of men on first beginning their watch to clean their fires and clear the bars of all clinkers or vitreous matter, according as each fire burns down for the first time after taking charge. By this means the men are made responsible for the condition and efficiency of their own fires during their watch; and before leaving, they should clear out the ashes from the ash pits, collect the cinders to be re-burnt, and throw the refuse overboard.

Forcing the Fires is expensive of Fuel.—If it is found that the boilers do not generate the requisite supply of steam, it will then be requisite to urge the fires to a greater extent by the frequent use of the "slice," which is inserted from underneath between the bars, in such a manner that the coal is raised and broken up, and a larger supply of air is permitted to pass through. It is evident, however, that in this case a considerable waste must ensue from the cinders falling through the bars into the ash pit before they are thoroughly consumed, and these cinders cannot now be again thrown on the fire, because it is necessary that the combustion should be as bright and active as possible, in order to "keep the steam."

The Cinders to be re-burnt when practicable.—Hence this valuable fuel is thrown overboard; but in well-constructed boilers of sufficient capacity for the easy supply of the engines, a considerable economy will result from carefully separating the cinders from the ash and re-burning them. When using Welsh or other coals that are easily broken, it becomes of special importance that the fires should be allowed to burn regularly, without being frequently broken up or disturbed, for as these coals contain a large proportion of *small* and dust, this would be entirely lost by falling through the bars were the fires much worked. When, on the contrary, this small coal is thrown over the fire and allowed to cake, it then becomes available; but as it deadens the fire when first thrown

on, this cannot be done unless the boilers are large enough to generate a sufficient supply of steam with "dead" or slow-burning fires.

Superior Economy of Large Boilers.—Hence arises a principal source of economy from the use of boilers of ample capacity to generate the steam without the fires being unduly disturbed, and it is believed that on this ground alone can the alleged superiority of slow over rapid combustion be maintained, in cases where the flue surface is supposed sufficient to absorb a fair proportion of heat generated.

The Boiler Power is usually subdivided into Sections.—In large steam vessels the boiler power is usually subdivided into two or four sections, each independent of the other, and capable of being connected together or disconnected, at pleasure. In such vessels it frequently happens that the full steam power is not required, so that a fourth part, or even a half of the steam which the boilers are capable of generating, may be dispensed with. When this is the case it is the usual practice for the engineer to disuse either one or two of the boilers altogether, urging the remaining sections so as to make them generate the full quantity of steam of which they are capable.

How to manage the Boilers when full Steam is not wanted.—It is now recommended, however, that instead of disusing entirely any one of the boilers, they should all be kept in use, the fuel being burnt slowly and equally upon the fires. By this means not only will the fuel be used more economically in the furnace, but an additional advantage will be derived from the flue or tube surface (in a marine boiler always more or less insufficient), which will now be enabled to absorb more of the heat generated. In like manner, where one-half of the steam power is sufficient, one only of the four sections should be disused. This is considered preferable to using all the four in such a case, as it is difficult in practice to carry out the system

of slow combustion to its extreme limits; because, when small quantities of coal are spread over the fires at long intervals between, they are apt to burn into holes and admit the entrance of jets of cold air, which rob the flues of their heat. If, however, the engineer in charge can surmount this difficulty, either by skill in managing the fires or by bricking over a portion of the grate surface in each fire (which is perhaps the best mode of proceeding), he might then continue to use all the four boilers with decided advantage.

Lord Dundonald's Experiments on Slow Combustion in Marine Boilers.—The beneficial results which may be obtained from slow combustion, combined with large absorbing surface, in a marine boiler, have been clearly proved in a series of experiments conducted by Lord Dundonald, in H. M. dockyard, Chatham. The weight of water evaporated by one pound of coal in marine boilers of the usual proportions varies from eight to ten pounds, whereas in those constructed by Lord Dundonald for the *Janus*, 12·9 lbs. were evaporated. This high result was attributed by his Lordship to the more effectual burning of the coal by "slow combustion" combined with a peculiar arragnement of the flues and tubes constituting the absorbing surface of the boiler, which, it must be kept in mind, was nearly double the size usually allowed for the supply of the same quantity of steam.

In order to carry out this principle, therefore, in vessels constantly using their full power, the boilers would have to be made nearly double their present size, which in most cases is wholly impracticable, and is certainly not to be recommended.

Experiments with a Tubular Boiler in Woolwich Dockyard.—To form a comparison with these results the furnaces of a common tubular boiler, such as are used in the Royal Navy, and which was at the time lying in Woolwich dockyard, were partially bricked up—the absorbing surface remaining the same as before. The result now obtained was quite equal to

that from the boilers of the *Janus*, although the rate of combustion per square foot of grate-bar surface was more rapid in the case of the Woolwich boiler. It is evident, therefore, that this boiler, when altered, was in precisely the condition into which marine boilers not required to generate their full quantity of steam, may and should be brought by the engineer in charge, whenever the occasion presents itself. In the above instance, a saving of about one-third of the fuel was thereby effected, although, as a necessary consequence, the quantity of steam which the boiler was capable of producing in a given time was diminished to nearly one-half.

The experiments above referred to are of considerable value, as indicating the economy of slow combustion on the bars of a marine boiler (when this is practicable), as well as the relative effect on the evaporative power of the boiler produced by a progressive diminution of the grate-bar surface, as will be seen from the subjoined table (page 59).

Dimensions and Description of the Experimental Boiler.—The boiler experimented upon was an eighty-horse tubular marine boiler of the ordinary construction, with horizontal tubes over the furnaces. Its extreme measurements were 9 ft. long by 8 ft. 6 in. wide, covering an area of 76½ sq. ft. in the vessel, or ·956 sq. ft. per horse power. It had three fires, each 8 ft. by 2 ft. 2 in., affording 93·6 sq. in. grate surface per horse. The total "effective" heating surface, after deducting one-third for the bottoms of tubes, was estimated at 13 sq. ft. per horse-power. There were 176 iron tubes, each 3 in. outside diameter, and 6 ft. long. The boiler was 12 ft. 2 in. high, and the furnaces 2 ft. 10 in. high. Capacity for steam was 167 cub. ft. Total space occupied by the boiler, 761 cub. ft. Total evaporating surface in the boiler estimated at 1057 sq. ft.

Dimensions of the Boilers of the Janus.—There were four boilers originally in the *Janus*, each measuring 12 ft.

2 in. by 8 ft. 4 in., and covering an area of 406¼ sq. ft. in the vessel, and three fires in each boiler, each 6 ft. by 2 ft. 1½ in. The boilers are 14 ft. high to top of steam chests; the total space occupied 4,738 cubic feet. The total evaporating surface, measuring the outside of the tubes, as in the Woolwich boiler, is 5137·4 sq. ft. The North-country and Welsh coals having been mixed in the stores at Chatham dockyard, where the trials were ordered to be made, it was necessary to select by hand lumps of Welsh coal for the trials; and, to render the comparison fair, this was done in the latter trials of the Woolwich boiler also. From this cause the results in both cases are beyond the average.

Regulation of the Draught.—Where it is not convenient to lessen the grate-bar surface by bricking up the bars at the further end, the same object may be effected, though certainly not so economically, by checking the draught. With this object in view, every boiler should be provided with damper doors upon the mouths of the ash pits, accurately fitted, and furnished with the means of regulating with nicety the amount of air entering beneath the bars, or, if necessary, of excluding it altogether. Dampers are besides fitted at the foot of the chimney, but these are not so completely under control, nor do they admit of the draught of each fire being regulated separately.

Air-valves for the admission of air above the fire bars are now sometimes fitted in the furnace doors, with the view of "burning the smoke," but with very doubtful success. It has been already shown how difficult a matter it is to consume the smoke economically after it has been once formed, the true principle being to prevent, as much as possible, the formation of smoke at all.

In Prideaux's Patent Furnace-fronts, which are sometimes fitted to marine boilers, the fire doors are made of movable strips, like Venetian blinds, which are opened by the

act of opening the door to throw on coals. They then close gradually (as the fire burns clear) by means of a self-regulating apparatus, consisting of a little cylinder containing water and fitted with a weighted piston which, in its descent, drives the water in the cylinder through a small orifice from the under to the upper side of the piston. The bars of the Venetian fronts, being attached to the piston-rod, are shut as the piston descends, which takes place in six or eight minutes after the furnace has been fed. They are objectionable at sea from being heavy and unmanageable when the ship is rolling, so that the doors are kept open too long during the operation of firing, and the furnaces consequently cooled. We have been assured by engineers who have tried them, that they require an additional fireman to attend upon them, and that there is no appreciable saving from their use. I can believe that on shore they may be found advantageous, although they are evidently too cumbrous and troublesome on board ship, where so many fire doors have to be opened in rapid succession. Their expense, also, must be considerable.

Banking up the Fires.—Cases frequently occur in which it becomes an object to check the rapid formation of steam for a longer or shorter period, but at the same time to retain the power of getting up full steam and starting the engines again on the shortest notice. This is done by pushing the burning fuel back against the bridge, and covering it with wetted small coal and ashes, by which means the fires will be kept in a smouldering state, ready to be broken up and spread over the bars when the order is given to get up the steam. But as this process requires at least twenty minutes before the fires can be brought to their proper state of efficiency, it is better, when such notice cannot be reckoned upon, merely to push back the fires and heap them up against the bridge, raking them forward again when required.

To get the Steam up rapidly.—It is of great importance, when wishing to get up the steam rapidly, to take care that

the fire bars are so covered by coal, that a current of cold air is not allowed to pass through the flues, mixing with the small quantity of smoke or products of combustion at first formed. Everything should be done to facilitate, or, if possible, cause a draught of air into the ash pits.

No Water to be thrown into the Ash Pit.—It is a most reprehensible custom amongst firemen, and one which should not on any account be permitted, to throw water upon the ashes in the ash pit. They should be drawn out, and the best of them, roughly separated by the shovel, be thrown again upon the fire, while the remainder should be drawn well away from the boiler and gradually quenched with a stream of water from a hose, so as not to fill the engine room with steam and dust, nor keep the front of the boilers constantly wet, so as to corrode and destroy them at this spot.

TABLE OF EXPERIMENTS WITH A TUBULAR MARINE BOILER OF EIGHTY-HORSE POWER, MADE IN H.M. DOCKYARD, WOOLWICH.

No. of Experiment.	Duration of Experiment.	Dimensions of the Furnaces.	Total Surface of Grate Bars.	Bar Surface, per cub. ft. evaporated per hour.	Kinds of Coal used in the Experiments.	Quantity of Coal used.	Quantity of Water evaporated.	Ratio of Effect at Temperature of Feed.	Ratio of Effect with Feed at 100°.	Evaporation in hour in cub. ft. with the Feed at 100°.	Ratio of Effect in Proportion to Bar Surface.	Coals burnt per sq. ft. of Bars, during the Experiment.	Coals burnt per sq. ft. of Bars per hour.	Temp. of the water supplied to the Boiler.	Evaporating Surface per cub. ft. of Water evaporated per hour.
No.	h. m.	ft. in. ft. in.	sq. ft.	sq. ft.		lbs.	lbs.			cub. ft.		lbs.	lbs.	Deg.	sq. ft.
1	6 30	8 0 × 2 2	52	·515	Welsh Coal.	4648	41,040	8·83	9·18	105·06	8·83 : 1	89·38	13·75	56	10·06
2	5 50	,, ,,	,,	·489	Lewis' Merthyr.	4704	38,760	8·24	8·58	110·76	8·38 : 1	90·46	15·51	54	9·54
3	8 6	,, ,,	,,	·825	Wood's do.	3808	31,920	8·38	8·73	65·69	14·14 : 1	73·23	9·04	54	—
4	2 55	5 3 × 2 2	34·125	·546	,, ,,	1176	11,400	9·69	10·11	65·21	9·36 : 1	34·46	11·81	53	16·22
5	6 20	,, ,,	,,	·658	Lewis' Merthyr.	1904	20,520	10·78	11·23	54·01	11·28 : 1	55·77	8·81	54	19·57
6	6 24	,, ,,	,,	·499	,, ,,	2576	27,360	10·62	11·07	71·32	8·55 : 1	75·49	11·79	53	14·82
7	5 55	4 0 × 2 2	26	·351	Handpicked.	2632	27,360	10·39	10·87	77·35	6·02 : 1	101·23	17·11	50	13·66
8	5 58	8 0 × 2 2	52	·773	,,	2352	25,080	10·66	11·18	70·49	13·25 : 1	45·23	7·58	47	14·99
9	4 10	4 0 × 2 2	26	·495	,,	1120	13,680	12·21	12·80	55·06	8·49 : 1	43·08	10·34	47	19·19
10	6 5	4 0 × 2 2	26	·482	,,	1680	20,520	12·21	12·85	56·86	8·49 : 1	64·61	10·62	41	19·20
EXPERIMENTS MADE WITH TWO OF LORD DUNDONALD'S BOILERS, AS MADE FOR THE "JANUS."															
1	6 0	6 0 × 2 1	75	·5	Hand-picked and Llangennock.	4558	56,277	12·34	12·901	156·9	12·34 : 1	60·77	10·13	50	16·37
2	6 0	6 0 × 2 1	75	·51		4600	54,920	11·94	12·483	153·1	12·597 : 1	61·33	10·22	50	16·77
3	6 0	5 0 × 2 1	62·5	·437		4700	53,770	11·44	11·96	149·9	10·769 : 1	75·2	12·53	50	17·13
4	6 0	6 0 × 2 1	45·83	·4 1		3600	41,784	11·6	12·127	116·4	10·14 : 1	78·55	13·1	50	22·06

CHAPTER V.

THE MARINE BOILER: MANAGEMENT OF THE WATER AND STEAM.

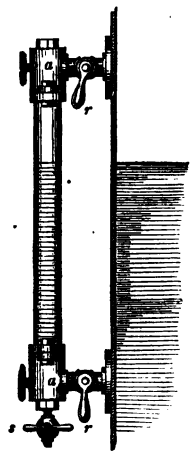
Supply of Water to the Boilers.—The keeping up a due supply of water in the boilers demands the utmost care and watchfulness on the part of the engineer, for should the iron in any place be allowed to become red-hot from want of water, an explosion is almost inevitable. The immediate effect of the heat upon the unprotected plates is to warp and distort them, causing them either to separate at the joints by the giving way of the rivets, or to be torn asunder by the elasticity of the steam acting upon the distorted and softened surface. Explosions have also frequently taken place from water having been too suddenly admitted to the hot plates in the eagerness of the engineer to make up for his previous neglect, when steam is generated so rapidly that the safety valves are insufficient for its escape. It is said that in such cases a portion of the water, becoming decomposed into its elements by contact with the red-hot iron, may form an explosive compound of oxygen and hydrogen gases, which, on ignition, causes the explosion. But whatever the theory, the fact itself is indisputable that explosions do frequently occur in this way; and should the engineer ever find himself in such a predicament he must instantly draw his fires, and *then* add water very sparingly and cautiously until the plates be again cool.

The Water Level must not rise too high.—Danger of another kind is to be apprehended if the water level is allowed to rise too high in the boilers, for the water may then boil over into the steam-pipe, or if the steam space be already somewhat contracted, it may increase the "priming" of the

boilers to a dangerous degree, for nothing is found to tend more to this most troublesome evil, than too limited steam room.

Water Gauges.—To guard against such accidents as these, every boiler is fitted with two different sets of apparatus for indicating the water level, and thereby guiding the engineer in the admission of the feed. These are called the "glass water-gauge," and the "water-gauge cocks."

Glass Water Gauge.—The first apparatus consists of a glass tube about eighteen inches long, fitting into brass sockets at top and bottom, by which it is connected vertically to the front of the boiler, in such a position that when the boiler is filled to the proper height, the water level may coincide with the centre of the tube. This tube is furnished with three stop-cocks, one at *r*, leading from the top into the boiler *above* the water level, another at *r* from the bottom into the boiler *below* the water level, and the third at *s*, lead- from the tube itself into the stoke-hole through a small pipe. When a communication is opened therefore, at *a a*, between each end of the tube and boiler, the water, being subjected to the same pressure of steam as within the boiler, will stand in the tube at the same height, thus accurately showing the water level. As the tube, if left to itself, is apt to become choked with salt or deposit (especially if the water be dirty), the third cock is provided, and by occasionally opening this, the rush of steam and water through it clears away all obstructions. Should there be much ebullition at the part of the boiler where the gauge is fixed, the level of the water in the glass will be very



unsteady, and this must be remedied if possible by leading a small pipe from the top of the tube into the crown of the boiler, where the steam is drier, and at the same time sinking another small pipe from the bottom of the tube into some place where the water is less agitated. It is also of importance that the gauge be fixed nearly in the centre of the front of the boiler, so as to be as little affected as possible by the rolling motion of the vessel. The last two remarks apply equally to the brass gauge cocks.

Brass Gauge Cocks.—In case of accident to the glass water gauge three gauge cocks are fitted besides, one above the other, at six or eight inches, distance between, the middle one being placed at the average water level of the boiler. Upon opening these therefore, successively, steam ought to issue from the upper one, water and steam from the middle one, and water alone from the bottom cock, and any variation from this will clearly indicate that the water is either too high or too low in the boiler. These cocks should be frequently opened, as they are also liable to become choked up with salt or deposit. As the surface of the water in the boiler is generally at a higher level than can be conveniently reached from the firing stage, the gauge cocks may be fixed at any convenient height to the front of the boiler, and pipes led up inside to the respective heights.

Only One Feed Pump to be worked.—Although each of the feed pumps is made capable of supplying the full quantity of water required by the boilers, it is nevertheless the practice in many steam vessels to keep both the pumps constantly at work, the surplus water which is rejected by the boilers being returned to the hot well, or thrown overboard. This practice, arising from an over-anxiety for an abundant supply of feed water, is much to be deprecated; as when the pumps are both kept working, a partial failure in either of them may escape detection until one meets with an accident,

and is rendered useless, when it is probably found that the other pump is also out of order, and is insufficient to do the full duty alone. In such a case recourse must be had to the supplementary pumps, which are always fitted for the purpose of feeding the boilers when the engines are not at work.

Amount of the Brine abstracted.—We have already adverted to the necessity which exists for abstracting from the boiler a certain proportion of the super-salted water, in order to prevent the deposition of scale or salt upon the plates. The amount thus abstracted, or "blown off," as it is technically called, varies with the quantity of the salt and other impurities contained in the water, but this may be stated to vary from about one-fourth part to one-half of the whole feed water admitted.

Proportions of Salt in Sea Water from different Localities.—According to Dr. Ure's experiment, the largest proportion of salt held in solution in the *open sea* is 38 parts in 1000 (by weight), and the smallest 32. In a specimen brought from the Red Sea, 43 parts were found, the specific gravity of the water being 1·035. The Mediterranean contains about 38 parts, the British Channel, 35·5; the Arctic Ocean, 28·5; the Black Sea about 21; and the Baltic only 6·6.

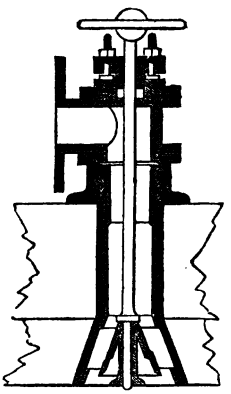
Analysis of Deep Sea Water.—The same authority states that deep sea water, from the ocean, from whatever locality, holds nearly the same constituents in solution, containing, on an average, in 1000 parts,

25 of Chloride of Sodium (common Salt).
5·3 Sulphate of Magnesia.
3·5 Chloride of Magnesium.
0·2 Carbonates of Lime and Magnesia.
0·1 Sulphate of Lime.

34·1;

besides a little sulphate and muriate of potash, iodide of sodium, and bromide of magnesium.

Blowing off.—The operation of "blowing off" is performed either by hand, or by brine pumps worked by the engine, the brine being in either case constantly and uniformly abstracted in a fixed proportion to the feed water. Brine pumps used to be generally preferred for this purpose, but it is now found that they are unnecessary complications. The usual practice, which appears to answer every purpose intended, is to blow off continuously, through a pipe and cock capable of nice adjustment by hand, a portion of brine regulated according to the degree of saltness of the water in the boiler, as ascertained by hourly trial with the salinometer. It is preferred to blow off mostly from the surface, the insoluble particles from which the scale is formed being ballooned up to the surface of the water on bubbles of steam, and kept dancing about there, until they find an opportunity of aggregating and falling to the bottom through the more quiescent portions of the water spaces. Hence, it is usual to fix a shallow pan of considerable size, called a scale pan, at six or eight inches below the surface of the water, into which these insoluble particles gradually settle, in consequence of the contained water being comparatively still—and it is from this "scale pan" that the surface blow-off pipe is led. The feed should naturally enter the boiler at a point as remote as possible from the blow-off. In addition to this apparatus, another blow-off cock is always fitted on the bottom of the boiler, which should be used occasionally during the voyage, and which is required for blowing the water out of the boiler by the steam pressure when the fires are drawn. Where the blow-off passes through the ship's side, a *Kingston's valve*, as shown in the margin, is invariably employed.



Kingston's Valve, applied as Blow-off Cock.

Brine Pumps were introduced by Messrs. Maudslay, and improved by Seaward, who connected the valve for the exit of the brine with that for the admission of the feed, so that the two open and shut together; and as their areas are proportioned to each other in the proper ratio, no more brine escapes than is demanded by the evaporation of the boiler. The brine pipe is further fitted with a cock for its better regulation, or in case it may be wished to shut it off altogether, when using fresh water in the boilers. When the simple operation of blowing off is properly performed, the boilers may be kept almost perfectly free of scale at a trifling expenditure of fuel, certainly not exceeding 4 or 5 per cent. of the whole fuel burnt. For it is evident that the brine blown off has had its temperature raised by about 120° only (viz., from 100° temperature of the feed to 220° temperature of the brine), a considerable part of which heat is again given back to the feed during its passage through the "refrigerators," should such be fitted.

The Refrigerator.—The hot brine, ejected at a temperature of perhaps 218°, is generally made to pass through a cylindrical vessel called the "refrigerator," containing a number of copper tubes, through which the feed water, at a temperature of about 100°, circulates on its way from the hot well to the boiler. A considerable portion of the heat of the brine being by this means transferred to the feed, is again returned to the boiler, and a proportionate saving in fuel is effected.

Attempts made to Supersede Blowing off.—It has been attempted in various ways to modify the usual manner of blowing off, and with this end in view a chemical solvent has been added to the water of the boiler, which it is intended shall act upon its mineral impurities without injuriously affecting the iron plates. The utmost that can be done, however, by even the most successful of these schemes, is to prevent the formation of a hard crystalline scale; the impurities being

now deposited in the shape of a loose powder, from a state of mechanical suspension in the water. This powder, then, must still equally be removed by partial blowing off, if we would preserve the water from loss of heat by imperfect conduction, or the plates from danger of being burnt. For, since pure water alone can leave the boiler in the form of steam, it follows that all the foreign constituents must remain behind, however they may be disguised by chemical combination; and, unless this mineral solution be removed too, it must of necessity reach a limit at which the bases will be deposited, the point of saturation being deferred in proportion to the solvent power of the solvent employed. It is also the case, as we shall presently see, that the greater the degree of saturation, the more heat is required to bring the water to the boiling-point, and the hotter therefore is that portion of brine which must, under any circumstances, be got rid of. There is also danger to be apprehended from the chance of an improper or too powerful solvent being employed, which may act injuriously upon the materials of the boiler. This plan, therefore, has been totally disused.

Salinometers.—Since the freedom of the boiler from scale or deposit depends, as we have seen, upon the greater or less degree of saturation of the water, it is an object of much importance to be able to test the saltness of the water with ease and certainty. This may be done in two ways, each of which the engineer should have the means of trying from time to time; namely, by ascertaining the true boiling-point of the brine at the pressure of the atmosphere, and by finding its specific gravity at a given temperature—the strength of the solution maintaining a fixed and known relation to its boiling-point and specific gravity. The instruments to be used are therefore the *Thermometer* and the *Hydrometer*.

The Thermometer used as a Salinometer.—In using the thermometer for this purpose, an instrument must be selected in which the scale is graduated in large degrees, capable of

being subdivided into quarters, at least; but the scale need not extend beyond twenty degrees above and below the boiling point of water. Such thermometers are in use for ascertaining the heights of mountains, by observing the temperature at which water boils at the top. This fact, of itself, plainly demonstrates the dependence of the boiling-point of liquids upon the pressure, and it is therefore necessary always to take the pressure of the atmosphere into account. When we say that water boils at 212°, it is understood to mean when subjected to the *usual* pressure of the atmosphere, indicated by a column of 30 inches of mercury in the weather barometer at the level of the sea.

The following table shows the boiling-point and specific gravity of sea water (at 60° Fahr.) of different degrees of saturation, expressed in parts of salt contained therein, the barometer indicating 30 inches of mercury.

	Saltness.	Boils.	Sp. gr.	
Pure Water . .	0	212°	1·	
Common Sea Water .	$\frac{1}{32}$	213·2°	1·029	
	$\frac{2}{32}$	214·4	1·058	
	$\frac{3}{32}$	215·5	1·087	
Up to this point no deposit will be formed .	$\frac{4}{32}$	216·7	1·116	
	$\frac{5}{32}$	217·9	1·145	
	$\frac{6}{32}$	219·1	1·174	
	$\frac{7}{32}$	220·3	1·203	
	$\frac{8}{32}$	221·5	1·232	
	$\frac{9}{32}$	222·7	1·261	
	$\frac{10}{32}$	223·8	1·290	
	$\frac{11}{32}$	225·0	1·319	
	$\frac{12}{32}$	226·1	1·348	saturated solution.

As a general rule, the atmospheric boiling-point of the water should never be allowed to exceed 216°. The temperature must be ascertained by drawing off a small quantity of the brine, and boiling it in a deep copper vessel in the engine room, a correction being made, if necessary, for the state of the barometer.

The following Table shows the height of the boiling-point in Fahrenheit's scale at different heights of the barometer.

Barometer.	Boiling-point.	Barometer.	Boiling-point.
27 inches.	206·96°	29½ inches.	211·20°
27½	207·84°	30	212°
28	208·69°	30½	212·79°
28½	209·55°	31	213·57°
29	210·38°		

It will be seen that if we would preserve the water of the boiler at a degree of saturation indicated by $\frac{2}{32}$ of salt, we must blow off one-half of the feed water; if at $\frac{3}{32}$, then one-third must be blown off; at $\frac{4}{32}$, one-fourth, and so on. We have said that $\frac{3}{32}$ is the highest degree of saturation that should be permitted. The degree of saturation of the water should be tested at least once every hour.

The Hydrometer used as a Salinometer.—The hydrometer employed for measuring the density of water, or other liquids, consists of a hollow ball of glass or metal from which there rises a tall stem graduated with degrees, and ballasted so as to swim upright, the graduated stem being more or less immersed in proportion to the density or specific gravity of the liquid. The brine, therefore, increasing uniformly in density according to the salt it contains, may by this means be very conveniently tested; but as the densities of fluids vary also in proportion to their temperature, care must be taken that the portions of brine experimented upon have the particular temperature for which the scale of the salinometer has been calculated.

Annexed is a table of specific gravities of sea water at 60° Fahrenheit, in various parts of the globe, as ascertained by Dr. Marcet.

	Sp. gr.		Sp. gr.
Arctic Ocean . .	1·02664	Sea of Marmora .	1·01915
Northern Hemisphere	1·02829	Black Sea . . .	1·01418
Equator	1·02777	White Sea . . .	1·01901
Southern Hemisphere	1·02882	Baltic	1·01523
Yellow Sea . . .	1·02291	Ice Sea waters . .	1·00057
Mediterranean . .	1·02930	Dead Sea	1·21100

The specific gravities corresponding to various degrees of saturation of the sea water have been already given.

Seaward's Salinometer.—To obviate the inconvenience of withdrawing the water from the boiler, in order to test its specific gravity, Messrs. Seaward have invented a salinometer of which the following is the description. It consists of a strong glass tube of about three-quarters inch bore, and fourteen inches long, firmly fixed at each end in a brass frame, to which are attached four cocks, one at each end and two at the side. By the two latter cocks the instrument is attached to the front of the boiler, being fixed at such a height that the water line in the boiler may show its level in the glass tube. Now, upon opening the two cocks which are attached to the boiler, the water will rise up from the bottom of the boiler, by a pipe attached to the lower cock, to the same level as in the boiler. These cocks are then closed and the upper one opened, and two metallic or glass balls are dropped into the tube. The ball first dropped in has been graduated to swim when the water of the boiler is one degree salter and denser than the proper degree of saturation; and the second ball to sink when the water has become one degree more diluted and lighter.

The upper cock is then closed, and the two cocks communicating with the boiler remain open. It is evident, therefore, that when the water in the boiler is at the degree of saturation intended to be maintained, the lighter ball will float at the water level, and the heavier ball remain at the bottom; and further, that any change of density will alter the position of the balls, the lower ball rising as the water becomes more saturated, and the upper one sinking upon the water becoming more diluted. The upper and lower cocks are for the purpose of changing and cleaning the balls when required, the bore of each cock being equal to the diameter of the balls.

Cases in which the Amount of Blow-off may be diminished.—In the case of a vessel going at half speed, when the full

quantity of steam is not evaporated, the quantity of water blown off may of course be proportionally diminished, unless it be wished to take advantage of this circumstance and freshen the water in the boiler while it may be done without checking the power of the engines. For it is apparent, that the less water is blown off, so much less feed need be admitted to cool the boiler, and so much the more steam is generated. This renders it sometimes expedient, under critical circumstances, to stop the supply of feed altogether for awhile, in order to ensure an abundant supply of steam to the engines, and it is the duty of an intelligent engineer to provide for such emergencies, if possible, by having a good supply of water in the boilers beforehand. In making "trials of speed" of steamers, this is a usual jockeying trick.

In case the Blow-off Cock sets fast.—In the case of the blow-off cocks or any of the apparatus on board for withdrawing the brine from the boilers becoming choked or getting out of order, water must either be let out of the boiler by some means into the bilges, or it may sometimes happen that one of the systems of feed-pipes may be made available to allow the escape of water into the sea. A usual plan is to knock out a rivet from the bottom of the boiler.

Safety Valve.—The area of the safety valve should obviously be proportioned to the evaporative power of the boiler; but it is usually made in the proportion of half a square inch to each horse-power of the engines, which in the generality of cases is ample enough. Some manufacturers, however, do not allow more than a quarter of a square inch per horse-power, which can hardly be considered sufficient. It is loaded by the manufacturer to the extent best suited to the strength of his machinery, and this permanent load should not be augmented without his express sanction. The steam power of the vessel being subdivided amongst two or more boilers, each separate boiler (in the case of merchant steamers) is obliged

by law to have its own safety valve, which must be locked up beyond the control of the engineers or of any one on board, except the master, who keeps the key; but as an additional source of safety, and as a satisfaction to the engineers of the vessel, it is strongly recommended that a second, or open, safety valve be fitted in addition.

A properly constructed safety valve is not liable to get out of order, although, if suffered to lie long in contact with its seat without being raised, it will sometimes stick so fast as to defy all ordinary means of moving it. It should therefore be frequently tested by the engineer, to see that it moves freely.

With this view, and also as a ready means of relieving the pressure of steam when the vessel is lying to, a series of levers and jointed rods lead from the firing stage to the bottom of the valve spindle; being so contrived that the engineer may push the valve up off its seat, but at the same time offering no obstruction to the free rising of the valve by the steam pressure. It more frequently happens that the valve fits its seat so badly as to allow of the escape of steam. This should be guarded against by making the valve itself as solid and stiff as possible, and fixing the seating in a strong cast-iron valve box, which will not spring by the pressure of steam upon it.

In case the Safety Valve sticks fast.—Should it happen that the safety valve of any one boiler becomes inoperative, the surplus steam will still have a free passage through the stop valve into the adjoining boiler, whose valve, it may be presumed, is in good order; but should this means of escape either not exist or prove inadequate to relieve the pressure, then the blow-through valves of the engines must instantly be opened, so that the steam may find an exit through the valve casing and condenser. The fire doors should at the same time be thrown open and the ash pit dampers closed, to check the fires as much as possible, before they are quenched with water, and drawn. The first indication of an excessive pressure is usually given by the mercury being blown out of

the mercurial steam gauge, where such is fitted, this acting to the best of its capacity as a safety valve also.

Steam Gauge.—The steam gauge usually fitted to marine boilers is a bent iron tube, like a siphon-tube reversed, attached vertically to the front of the boiler, one of the orifices opening into the steam chest, and the other open to the external air. The tube is partially filled with mercury, which of course stands at an equal level in both legs of the gauge, so long as there is no pressure of steam in the boiler. But as the pressure upon the surface of the mercury in the two legs becomes unequal, it is forced down the one leg and up the other, until the equilibrium is restored. Hence, a depression of one inch of mercury in the leg communicating with the boiler is followed by a corresponding rise of one inch in the other leg, but the difference of level between the surfaces of the mercury in the two legs is manifestly *two* inches. Thus, a rise of one inch indicates an additional pressure of one pound in the boiler, and not half a pound, as might at first sight be supposed. On the surface of the mercury, in the open end of the tube, there floats a light rod of wood, and this rising or falling with the level of the mercury, indicates the pressure upon a fixed scale of inches or pounds.

In addition to the mercurial gauge (which should always be fitted, as being the least liable of any to get out of order, and from its giving an alarm in case of the mercury being blown out by undue pressure) a spring pressure-gauge is usually added to each boiler, especially where tolerably high steam is used.

Vacuum, or Reverse Valve.—In addition to the safety valve, each boiler should be provided with a vacuum valve (of small dimensions), to prevent the possibility of the boiler collapsing, when the pressure of steam inside falls below the pressure of the atmosphere. This is frequently experienced in boilers whose supply of steam is insufficient for the engines, (as it is apparent that the latter may continue to work with a nega-

tive pressure in the boilers, provided there be a good vacuum in the condensers,) and it may happen to any boiler, by a sea breaking over the decks and suddenly condensing the steam. The action of this valve is sufficiently obvious, as it is only a reversed safety valve, slightly loaded; and the only attention it requires is, to try it occasionally, and see that the spindle moves freely.

Stop valves are usually placed on the mouth of the steam pipes, where they issue from the boiler, but occasionally at other points between the boilers and the engines, or upon the steam pipes connecting the boilers with each other. They are so arranged that each boiler may be quickly disconnected from the others in case of accident at sea, or when it is wished to discontinue its use, either for executing small repairs or for saving steam. The stop valves should always be placed exterior to the safety valves, so as not to interpose any obstruction between them and the steam in the boiler, this important provision forming the substance of a bye-law made by the Board of Trade. They are made either self-acting, so as to open by the pressure of steam from within the boiler, and shut by external pressure, or else to open and shut by a screw worked by hand.

CHAPTER VI.

ON EXPLOSIONS OF STEAM BOILERS.

THE causes which induce steam-boiler explosions are still enveloped in much mystery. The usual presumption in such cases is, either that the safety valve has not acted, and that the boiler has burst simply from excess of pressure; or that the water has been allowed to get too low, and that the plates, becoming red-hot by the action of the flame upon them, have suddenly generated such a rush of steam upon the re-admission of the feed, as to cause a rupture of the weakened plates, in consequence of the safety valve not having sufficient area to give vent to the steam. The idea that the steam itself is decomposed on coming into contact with the red-hot plates, is scarcely tenable, as the resulting hydrogen gas, even if formed, could not possibly explode without the presence of oxygen; which gas, at the moment of decomposition of the steam or water, must have combined with the hot iron, otherwise the hydrogen would not have been liberated. Explosions most frequently occur at the instant of opening or shutting a safety valve or communication valve, which seems to show that so long as the steam remains undisturbed within the boiler, it will sustain a very high pressure with impunity, but the moment that a wave or pulsation is carried through it, the previously existing equilibrium of forces is destroyed, and a rupture takes place at some one point. In the case of the flues having become red-hot for want of water, the steam would also have become super-heated from contact with the hot plates, and we can easily conceive that the sudden addition to it of a large quantity of common or saturated steam, holding much water in mechanical suspension, would increase the pressure with explosive rapidity. The very act

of suddenly opening a safety valve or stop valve, would cause the water to boil up violently against the hot plates, and to mingle with the super-heated steam, thus greatly increasing the danger. In the event, therefore, of the discovery being made that any part of the flues has become over-heated from want of water, the engineer is admonished neither to open the safety valve nor admit the feed, but instantly to open all the fire doors, close the dampers, and draw the fires, after which the safety valve may be cautiously relieved, and the feed admitted by a little at a time, until the hot surfaces are all covered.

When the water spaces of two boilers are connected either by the feed pipes or by a connecting pipe, care should be taken that a little extra pressure on the one boiler does not force the water out of it into the adjoining boiler. When the usual glass water-gauges are fixed in a part of the boiler much exposed to ebullition, or when the water in the boiler gets very dirty, they are not to be depended upon for a correct indication of the water level, and in all cases the water will show a little higher within the gauge when the engines are in motion, than when they are at rest.

The place where a boiler frequently gives way is the top of the furnace, or over the bridge, owing probably to the plates there getting over-heated from imperfect contact with the water. It is now generally believed that wherever water is in forced contact with a plate intensely heated, there is a tendency for the water to be repelled from the hot surface, and to a certain extent to acquire the globular form which we have all observed when water is poured on very hot iron. This repulsive action is also plainly seen when a lump of red-hot iron is plunged into a vessel of water, no hissing sound being at first produced, and comparatively little steam evolved, until the iron cools to a certain temperature. This temperature is stated to be about 350° Fahr., and it is worthy of remark that so soon as the globules of water cool down to this temperature, they immediately flash into steam. Now, sup-

posing this action to be going on inside a boiler, and feed water to be suddenly injected, so as to lower the temperature to 350°, an immense accession of steam would be the immediate result. It is very desirable therefore (on many accounts) to prevent the flame and heat from being unduly concentrated at any particular place, and to have plenty of water (eight or ten inches at least) over the parts which are necessarily hottest. A roomy fireplace, with plenty of space over the bars, will be found to diffuse the heat much more equally than a contracted one. Care must be taken also that the steam has free and rapid vent from every part of the heating surface, and that the water spaces are so constructed as to be easily accessible for cleaning or scaling, nothing being so likely to cause overheating of the plates as a hard deposit adhering to them. Plenty of steam room is also a safeguard to a boiler, as this tends to diffuse and neutralize the dangerous oscillations produced in the steam by suddenly opening or shutting a safety valve or communication pipe to the engines.

The immense rush of steam which always follows an explosion, and to which, along with the scalding water, any loss of life which may ensue from the explosion is generally owing, is satisfactorily explained when we consider that the instant the water contained in the boiler is relieved from pressure, it throws off steam with great rapidity, and continues to do so until the whole mass of water is reduced to the atmospheric condition of 212° Fahr. To make matters worse, the steam chests of at least two boilers are usually in communication.

Fusible metal plugs, formed of an alloy whose melting point represents a steam pressure which may be considered dangerous for the particular boiler, are required by law in France to be inserted in the shell of the boiler, the intention being that they should melt when the pressure gets too high, and draw the engineer's attention to the fact by allowing the steam to rush into the engine room. It is found however in practice that they cannot always be relied upon, since in the first place they are liable to become incrusted with scale, like

any other part of the boiler, which prevents their melting at the proper temperature; and in the second place, because the long-continued action of a high temperature upon an alloy of this kind (the chemical affinity between whose constituent parts is very weak), causes the more fusible portion to ooze out from the mass, and the less fusible to remain behind, so that when the danger arrives, the plug will not melt. The ordinary mercurial steam gauge is a much more reliable appliance for giving warning of a too high pressure, and should be fitted to all marine boilers. In boilers using very high pressures, the mercurial gauge becomes inconvenient from the great length of tube required, every fifteen pounds' pressure requiring to be balanced by a column of thirty inches of mercury.

We believe one of the most effectual preventives of explosions to consist in the extra safety valve recommended by the Board of Trade to be placed upon each boiler, one of the valves being locked, and the key kept by the captain, and the other left open, under the surveillance of the engineer. As our manufacturing engineers are generally of opinion that it is not desirable to have the only safety valve of a boiler placed beyond the reach of the engineer of the ship, it is to be hoped that they will see the expediency of fitting the extra valve, which is but a small addition to the original cost of the boiler, and is certainly an additional safeguard. The common conical valve, fitted in a strong cast-iron valve chest, appears to be the best that can be employed. It is also strongly recommended that no stop valve of any description should be interposed between the steam of the boiler and the safety valve.

Explosion on board the Parana.—It is highly probable that the lamentable accident on board the *Parana* was caused by an impulse or percussion of steam acting upon a weakly-stayed boiler, since it is now ascertained that at the instant of the explosion a stop valve was closed, through which a large flow of steam was rushing at a high velocity into another boiler. The *Parana* has four boilers, two before and two

abaft the engine room, and on this occasion they had all been in use for an experimental purpose, and the steam was observed to blow off freely from a safety valve on each boiler (no more being fitted), at twelve pounds' pressure. The experiments having been concluded, the engineer made his arrangements for blowing out the water into the sea, through the blow off cocks, by the pressure of steam in the boilers. The fires of one of the starboard boilers having been previously drawn, the steam had fallen so low in it, that there was not sufficient pressure to expel the water, which was mostly below the sea level. As there was plenty of steam in the other starboard boiler, however, the engineer, naturally enough, applied the steam of the one boiler to blow the water out of the other, the steam chests of the two boilers communicating by means of a long straight pipe, about twelve inches diameter, which stretched between them for the whole length of the engine room. The steam was therefore rushing through this long pipe with great force, its velocity probably increased by the condensation which must have been taking place within the cool boiler, when its impetus was suddenly checked by the closing of the stop valve attached to the empty boiler. This, if done instantaneously, as it probably was, would inflict a sharp blow upon the valve, and a corresponding recoil through the pipe to the interior of the other boiler, the shock of the recoil being carried straight through the steam in the steam chest, and taking effect upon the plates of the boiler immediately opposite the mouth of the communication pipe,—and it was just at that place that the *Parana's* boiler actually exploded. Such an effect would be instantaneous, and beyond relief by a safety valve, unless one happened to be located near the place where the boiler was struck, which, in the *Parana's* boiler, did not happen to be the case. What is called the "percussive" force of steam has long been known to engineers, and deserves to be guarded against more than it is, in the fitting of stop valves and safety valves of boilers, which may easily be so arranged as to be incapable of opening or shutting too suddenly.

CHAPTER VII.

MANAGEMENT OF THE ENGINES.

Engine Room Signals.—

Engines Going.	*Engines Stopped.*
One Bell, Stand by engines.	One Bell, Go ahead.
Two Bells, Ease her.	Two Bells, Go astern.
Three Bells, Stop her.	Three Bells, Stop her.

The Bearings require Attention.—In the management of the engines, the points to be most attended to are the following. The bearings of all the working parts must be constantly watched, and regularly lubricated with oil or melted tallow. If the brasses are screwed or driven up too tight, the bearing will heat; if, on the other hand, they be too slack, a jar is produced at every revolution, destructive, if not positively dangerous, to the engine. As the brasses wear by the friction, therefore, they must be driven up to a moderate tightness by the cutters. As these are apt to work loose unless properly secured, it is now the practice to make the main cutters with a screw and nut at the point, to prevent this. When any of the main bearings heat, they must be slackened and bathed with melted tallow and sulphur; or, if the heating has proceeded to a great extent, a stream of cold water from the hose of the hand pump should be directed upon them. The bearings most liable to heat are those of the crank pin and crank shaft; but care must be taken, whilst cooling the latter, that the cold water does not crack the cast-iron plummer blocks. To avoid this, it must be thrown on very cautiously at first. The larger the surface of the bearing is in proportion to the friction to which it is subjected, the more easily it is kept cool and in good order, and the less oil is consumed in lubricating it.

To test the Tightness of the Engine before starting.—The following method of ascertaining the tightness of the different parts of the engine subjected to steam pressure is recommended to be used in every case after the engine has been fresh packed, or has been out of use for some time. After getting up steam, and while the vessel is still at her moorings, blow through, and then, after obtaining a partial vacuum in the condenser by the admission of a little water, watch the barometer, to see how long the engine holds her vacuum. If the condenser gradually becomes hot while the cylinder ports remain closed, we know that steam is passing the packing of the valves; or, if the valves are made without packing, the steam must be passing their faces. The tightness of the faces of D and other valves may be tested by shutting both ports to steam, and opening the cocks for taking indicator diagrams above and below the piston, the grease cocks, or any others communicating with the cylinder. If no steam passes through these cocks when the throttle valve is full open, the valve faces are then, of course, tight. The tightness of the piston may be proved in the same way, by admitting steam above or below it, and opening the indicator cock on the opposite side. The injection cock may be slightly opened for an instant, to withdraw any steam that may have collected on the opposite side of the piston, so that the passage of any steam may be the more readily perceived. The tightness of most parts of the engine may be tested in this way without moving it beyond half a stroke.

To discover a Leakage of Air into the Engines.—The engineer must watch strictly for leaks of air into the engines, by which the vacuum may be vitiated; as well as for every leakage of steam into the engine room. If the engine draws air on the "steam side," this may be discovered before it is set to work during the process of blowing through, when a jet of steam will be seen to escape; but if the leakage be suspected after the engines are at work, the engineer must endeavour to

discover it, either by the whistling sound of the rush of air, or, taking a lighted candle in his hand, pass the flame along all the joints till he finds it sucked in by the vacuum. Leakage in a horizontal joint may be readily discovered by laying water along it. An air leak may also be discovered by closing the snifting valve and the discharge valve at the ship's side, and filling the engines with steam. When the leak is found out, it must be stopped temporarily by driving in spun-yarn or gasket, steeped in red lead and oil, or other means.

A Cure of Leaky Condensers.—If the leakage be into the condenser, it is sometimes convenient to allow water to be injected through the orifice, by which means little harm is done. In several cases where, during a long voyage, the bottom of the condenser has become leaky by corrosion (often induced by galvanic action with the copper bolts of the ship's bottom, as well as the brass foot valve, etc.), a water-tight tank has been constructed at sea between the side keelsons. By this means the condenser and air pump are placed in a kind of well, constantly replenished with cold water from the sea, which, forcing its way through the leaks by the pressure of the atmosphere, shares with the proper injection water the duty of condensing the steam—the injection cock orifice being partially closed in proportion to the extent of leakage through the bottom.

Injection to be diminished when the Ship labours much.—When the vessel is labouring in a heavy sea, it is recommended that the supply of injection water should be diminished; for in such a case, where the speed of the engines is subject to great and constant fluctuations, depending upon the greater or less submersion of the wheels or screw propeller, the condenser is liable to become choked with water, thereby causing the engines to stop. The effect of working the engines with a stinted supply of condensing water is, of course, that the condensers will become hot, and the vacuum will be diminished;

but this is a minor evil in comparison with endangering the machinery by subjecting it to too severe a strain.

When the Injection Cock leaks.—Care must be taken, when the engines make a temporary stoppage, that the injection cock, or air pump, does not leak, and allow the condenser to fill with water, which causes much trouble and delay in starting the engines again; so, should this be apprehended, the sea cock must also be closed at the same time with the injection cock. It is also advisable to blow through at short intervals, to keep the condenser free of water, and admit a little injection water to keep up a vacuum, so as to be able to start upon the shortest notice.

Advantage to be derived from the Bilge Injection Pipes.—It is calculated that an engine requires about one ton of condensing water per horse-power, per hour; and it is apparent that the abstraction of this large body of water from *the bilge*, in case of the vessel springing a leak, constitutes a very valuable property in the machinery, and one which has ere now saved many steamers from foundering. It is essential, however, that the orifice of the bilge injection pipe be most carefully guarded against the entrance of chips of wood or oakum, which, by getting into the condenser, may gag the valves of the air pump, etc., and stop the engines. The bilge injection pipe should have no rose upon the orifice opening into the condenser, as such is liable to become choked; but the water should be spread by striking against a flat surface, or otherwise.

Injecting through the Snifting Valves.—Where no bilge injection has been fitted, a considerable body of water may be admitted into the condenser through the snifting valves, in case of a leak in the vessel. Should there be no means provided for lifting them, by stopping the injection and then blowing through, they will rise from the pressure of steam in

the condenser, when they must be prevented from closing again; or, should they be inaccessible, the cover of the foot valve, or the man-hole door of the condenser (if the water rise above it), should be slackened, to allow the water to enter.

To make Steam-tight Joints.—The usual mode of making air- or steam-tight joints between two surfaces, is to interpose hemp packing, or *gasket*, soaked in red or white lead and linseed oil, the joints being made when the steam is down, and screwed well up when the engine gets hot. If the joints have been accurately chipped and filed, then sheet lead, thick paper, wire gauze, etc., are usually employed, well smeared on both sides with red lead; or, if the joint has been planed and made perfectly true, then a little thin red lead is all that is necessary between the surfaces, to make them steam-tight. Cement joints are now almost wholly discarded from marine engines, and should never be made when there is a chance of the surfaces requiring to be again separated.

How to act in case of Accident to the Engines.—The various accidents to which steam engines are liable are so numerous, that any directions to meet particular cases are likely to be fruitless. Any engineer who expects a list of remedies for every evil that may occur, whether it be to smother a leak in a pipe with a stoker's fearnought dress, and lap it with spun yarn, or to fish an intermediate shaft, must be disappointed. He must rely on his own judgment when a flaw has shown itself or a fracture taken place, and consider carefully the direction of the strain, and take steps to provide for this; and also to guard against further injury if the weak part should give way. Wood and wrought iron are the materials with which all repairs at sea must be effected, and care should therefore be taken to have efficient means for adapting them to use when required. No hesitation must be felt regarding the unseemliness of a massive piece of timber to strengthen the frame of an engine;

and the principle of the expansion of wrought-iron straps or bolts by heat, so as to effectually tighten them, must not be forgotten. A clear perception of the principles of trussing, of leverage, and of the resolution of forces, is most important; and it is by such knowledge that a good and thorough mechanic will show his superiority in difficulties over the mere engine driver.

Test Cocks.—Small cocks should always be fitted to the top and bottom of the cylinders for clearing them of any water. They are generally constructed with a ball or reverse valve at their mouth, so as to allow of their being kept open without the entrance of air, when there is a vacuum on the side of the piston with which they communicate, which would injure the action of the engines.

Grease Cocks.—The grease cocks, for lubricating the pistons, must, of course, be opened only during the ascent of the piston, when the vacuum will suck in the melted tallow; otherwise it would be forced out by the pressure of steam. Those grease cocks on the slides, where there is a constant pressure of steam opposed to them, may generally be made to act by one man suddenly closing the throttle valve of the engine which it is wished to lubricate, while another opens the grease cock at the same instant; the throttle valve being reopened, and the whole operation performed as quickly as possible, so as not to stop the speed of the engine more than is absolutely necessary.

Turning the Engines by Hand.—One of the principal duties of the engineer, whilst in harbour, is regularly to move the engines round by hand through a portion of a revolution, in order to change the relative positions of all the touching surfaces. It is found, that when the iron piston-rod, for example, remains for even a day or two in contact with the brass gland, a slight, though perceptible, furrow is eaten in the rod by the

oxidation of the metal, induced by the galvanic action which results from the contact of the brass and the iron.

Galvanic Action.—The same destructive effect is produced in all the other parts of the machinery where copper or brass remains in contact with iron; but this proceeds more rapidly when sea-water or moisture of any kind is present, and according as the temperature is greater. In the case of paddle engines, the wheels present a convenient leverage for moving the engines by hand; but, with screw steamers, much difficulty is sometimes experienced in effecting this, and it has generally been found requisite to fit some mechanical contrivance for the purpose.

Essential to have square Regulating Lines marked on Marine Engines.—As spirit-levels and plumb-rules cannot be used on board ship, everything must be done by straight edges and squares. Every engineer, therefore, on taking charge of a pair of engines, on their coming out of the hands of the manufacturing engineers, should see that centre lines are scored well into the framing, at a sufficient number of parts, to facilitate any future examinations as to whether the engines have altered their position in any way, as well as to facilitate his putting the engines very correctly, when so required, at half stroke, and many other operations. Athwartship lines should certainly be scored in on the cylinder flanges, across the centres of the two cylinders, and on the base plates in beam engines, under the centre of the crank shafts. A fore and aft line in the centre line of each engine should also be scored in along as much of the base plate as possible. It is also usual in well-constructed engines to have four horizontal points in an athwartship line on the framing, dressed off so that four points in a true line on the face of a straight edge may lie upon the whole of them, and thus prove at any time whether the engines have fallen in towards each other, or fallen away towards the sides of the vessel.

To adjust the Paddle Shaft.—If the eye of the crank of the paddle shaft be perceived to bear hard upon the connecting rod brasses at one part of its revolution, and to separate from them at another part, the engineer may know that the centre of the paddle shaft is out of line with the centre of the intermediate shaft. To rectify this defect, place the engines on the top stroke, and measure the distance accurately between the faces of the two cranks at the side of the crank pin, then put the engines on the bottom stroke, and measure the distance at the same place. If the distance at the bottom be less, the outer end of the paddle shaft must be too low, and require to be raised. Subtract the one distance from the other, and take one-half of the remainder, and say, as the length of the crank is to the length of the paddle shaft, from the face of the crank to the centre of the outer bearing, so is this half-remainder to the amount that the outer bearing requires to be raised. Other examinations as to whether the crank and paddle shafts are true to each other, in other respects, can be made in a similar manner.

To replace the Levers on the Valve Shaft, if carried away.—The length of the valve lever is the distance from the centre of the valve shaft to the centre line of the valve spindle, with the addition of half of the versed sine of the arc through which it vibrates. The length of the gab lever must bear such proportion to the length of the valve lever that the traverse given to it by the eccentric shall produce the requisite amount of motion in the valves. The throw of the eccentric, multiplied by the length of the valve lever, must always be equal to the travel of the valves, multiplied by the length of the gab lever.

To fix the Gab Lever on the Valve Shaft.—The valve lever or levers being fixed upon the shaft, it must then be put in place on the engine, and turned round till the centre line of the valve lever is at right angles with the centre line of the valve spindle. The shaft being fixed in this position, the gab

lever is now to be put upon it in such a position that its centre line will be at right angles to a line stretched from the centre of the intermediate shaft to the centre of the gab pin on the end of the lever.

To find the Length of the Eccentric Rod, if carried away.—Place the valve shafts with the valve lever at right angles to the centre line of the valve spindle, and then measure the distance from the centre of the intermediate shaft to the centre of the pin of the gab lever, and this is the length from the centre of the ring of the eccentric rod to the centre of the gab at the other end of it.

To replace the Stops on the Intermediate Shaft for driving the Eccentric.—The eccentric rod being out of gear, place the engine right at top stroke, and place the valves in the position in which they ought then to be, that is, with the requisite amount of lead open to the steam. Now move the eccentric, which is loose upon the shaft, in the direction in which it would revolve if the engine was going ahead, until the eccentric rod drops into gear; the position of the stop for going ahead may now be marked upon the shaft, to meet the face of the stop upon the eccentric block. The gab of the eccentric rod being taken out of gear again without the engines or the valves having been moved, the eccentric block is now to be turned back, in the direction in which it would be revolving if the engines were going astern, and the eccentric rod will again drop into gear as it comes round, and this, in the same manner, gives the position of the stop upon the shaft for going astern.

Essential to know the Position of the Steam Valves from External Marks.—The valve rod being generally so fitted that its length can be varied with facility, for the sake of adjustment, it is essential that there should be a ready means of testing the correctness of its length at any time. This can only be done by a mark upon the rod, above the gland of the

valve bonnet or cover, this mark being made when the valve is at its mid-stroke, at a certain known distance above a mark on the flange of the valve casing or some other fixed portion of the engine framing. These marks are generally made by a centre punch well struck in; and a record of the required distance is made by another mark on the valve casing or framing, at the required distance. If the valve be placed at mid-stroke, the valve lever may now be connected with it, the only care requisite being, that the centre line of the valve lever shall be at right angles to the centre line of the valve rod, when the valve is in this position. If any doubt is entertained of the correctness with which the parts in question have been originally constructed, due examination of the steam ports and valve faces must be made, and the length of the valve rod and the marks tested. It is sometimes convenient to have a mark made on the framing, or some other ready means, by which it may be known when the valve lever is at right angles, as stated.

CHAPTER VIII.

USE OF THE EXPANSION VALVE, INDICATOR, AND DYNAMOMETER.

Principle of Expansion.—If steam be supplied to the cylinder of an engine at a uniform density during the whole length of the stroke, the resistance being at the same time uniform, the piston will move with a continually increasing velocity, until its momentum is suddenly and entirely destroyed, upon commencing the next change of direction, thus causing a destructive jar to the parts of the machine. To obviate this, therefore, the steam is "cut off" before the end of the stroke, which is then completed under a diminished pressure. By this means the piston comes gently to rest at the top and bottom of the cylinder; but this is neither the only nor the chief advantage which results from cutting off the steam, since it is found that *the force actually exerted upon the piston by the isolated steam, during its expansion into the increased volume as the piston descends in the cylinder, is considerably greater than that due to the simple pressure of the same weight of steam acting at a uniform density.*

To render this intelligible, let us suppose a cylinder of one square foot area, and twenty inches long, to which steam at about the atmospheric pressure has been supplied during half the stroke. We may then suppose the pressure on the piston to equal one ton at the moment the steam valve is closed, the space under the piston being open to the condenser. As the piston descends further, the steam above it will become diffused through an increased volume, and will consequently acquire a diminished pressure. We may assume that this diminution of pressure follows the law of elastic fluids in general, and that it decreases in the same proportion as the

volume of steam is augmented. While the piston, therefore, moves downwards from the centre of the cylinder (at ten inches), it will be urged by a continually decreasing force, until it arrives, we will suppose, at fifteen inches, when the space occupied by the steam will be increased in the proportion of two to three. The pressure on the piston will also be diminished in the inverse ratio of three to two; and will now equal two-thirds of a ton, at fifteen inches from the top. In like manner, when the piston arrives at the bottom, the space occupied by the steam will be double that which it occupied at half-stroke, and the pressure will be diminished one-half—being now, consequently, half a ton. By calculating in this way the pressure on the piston at the termination of each inch of the space through which the steam has been expanding, we find the pressure at the 11th inch expressed by $\frac{10}{11}$ of a ton; at the 12th inch $\frac{10}{12}$ of a ton; and so on to the 20th inch, where the pressure is $\frac{10}{20}$, or half a ton.

Now, if the pressure of the steam through each of these ten divisions be supposed to continue uniform, and, instead of diminishing gradually, to suffer a sudden change in passing from one division to the other, the mechanical effect will be obtained simply by taking the average of the ten pressures. Thus, it has been supposed, in the present case, that the pressure on the piston at the beginning of the first division is 2240 lbs.; and to obtain the pressures corresponding to each of the other divisions, it will only be necessary to multiply 2240 by 10, and divide successively by 11, 12, 13, etc. The pressures in pounds, at each inch below the half-stroke, will then be as follows, viz.:—

At end of 1st inch 2036·3 lbs.	At end of 6th inch 1400·0 lbs.
2nd „ 1866·6	7th „ 1317·6
3rd „ 1723·1	8th „ 1244·4
4th „ 1600·0	9th „ 1179·0
5th „ 1493·3	10th „ 1120·0

Benefit of Expansion.—If the mean be now taken by adding these numbers together and dividing by 10, it will be found

to be 1498 lbs. as the mean pressure of steam during the expanding half of the stroke, which is nearly three-fourths of the mechanical effect produced by the full steam during the first half of the stroke. In this calculation we have assumed, for the sake of simplicity, that the pressure is uniform throughout each of the ten divisions: which of course it is not, owing to the expansive action which takes place within each division; so, the more accurate calculation (which is a complicated one) makes the average pressure for the expanding half of the stroke equal to about 1545 lbs. It is evident that this principle is equally applicable at whatever part of the stroke the steam be cut off, a higher mechanical effect being obtained from a given weight of steam in proportion to the extent to which the expansive working is carried, and in proportion to the original density of the steam. Thus, in the Cornish engines, it is found to be most advantageous to use steam of from 30 to 40 lbs. pressure, and to cut it off in the cylinder at one-sixth, or even one-eighth part of the stroke, the remaining seven-eighths being performed wholly by expansion. The limit to this principle is imposed, in practice, by the increased size required for the cylinder, and the inequality in the speed of the piston during the stroke.

It is found, by calculation, that if the steam be cut off at half-stroke, its mechanical effect is multiplied by 1·7 nearly; if at one-third, by 2·1; if at one-fourth, 2·4 nearly; etc.

The following rule will be found useful for calculating approximately the mean pressure of steam on the piston during the stroke, while working expansively.

Rule.—Divide the length of stroke by the distance the piston moves before the steam is cut off, and the quotient will express the relative expansion it undergoes. Take from the annexed table the multiplier corresponding to this number, and multiply it by the full pressure of steam per square inch on entering the cylinder. The product will be the mean pressure per square inch, nearly.

TABLE OF MULTIPLIERS.

Relative Expansion.	Multiplier.	Relative Expansion.	Multiplier.	Relative Expansion.	Multiplier.	Relative Expansion.	Multiplier.
1	1·0000	2	·8466	3	·6995	4	·5966
1·1	·9957	2·1	·8295	3·1	·6875	4·1	·5880
1·2	·9853	2·2	·8129	3·2	·6760	4·2	·5798
1·3	·9710	2·3	·7969	3·3	·6648	4·3	·5718
1·4	·9546	2·4	·7814	3·4	·6540	4·4	·5640
1·5	·9370	2·5	·7665	3·5	·6436	4·5	·5564
1·6	·9188	2·6	·7521	3·6	·6336	4·6	·5491
1·7	·9004	2·7	·7382	3·7	·6239	4·7	·5420
1·8	·8821	2·8	·7249	3·8	·6145	4·8	·5351
1·9	·8641	2·9	·7120	3·9	·6054	4·9	·5284
2	·8466	3	·6995	4	·5966	5	·5219

The Indicator.—In practice, a much simpler and more accurate method is employed for finding the power exerted within the cylinder of a steam engine, namely, by the use of the indicator.

The Indicator, its Construction and Principles.—This little instrument, which ought to be familiar to every one entrusted with the care of machinery, consists of a small cylinder placed in connection with the cylinder of the engine, either above or below the piston. This cylinder is open at top, and is fitted with a piston which presses against a spiral spring. The cock which connects the indicator with the cylinder of the engine being opened, steam is admitted under the piston of the indicator during the one stroke, and vacuum during the other, precisely as in the large cylinders; thus causing the little piston to *push* or *pull* alternately against the spiral spring. If the pressure were uniform throughout the stroke, the indicator piston would start at once from the top to the bottom, and *vice versâ*, remaining stationary until acted upon by the opposite pressure. In such a case, the pressure exerted would be simply proportional to the flexure of the spiral spring, and

might be measured accordingly; but as we have seen that the pressure on the piston is continually varying during each stroke, it follows that the pressure on the spring must also be a variable pressure, corresponding to the movements of the indicator piston, either up or down. Now, if a pencil be fixed to the piston rod of the instrument, it will register the fluctuations of pressure upon a piece of paper held close to it; but, unless some provision be made for allowing the pencil a clear space on the paper at each successive instant of time, it will only move up and down in the same vertical line, and the markings due to fluctuation of pressure will be undistinguishable. To obviate this, the paper receives a circular motion in one direction during the down stroke of the piston, and a reversed motion during the return stroke, the result being that, as the pencil moves vertically up and down, a continuous curved line is traced upon the paper. By this line an oblong space is enclosed, called indifferently the *Indicator Figure, Card, or Diagram*, the vertical ordinates of which will then represent the effective pressure at the corresponding portions of the stroke, and whose area will represent the whole pressure exerted during the stroke.

Before the instrument is connected with the steam cylinder, the roller, with the paper attached, is set in motion, and the pencil then describes a straight line (called the *neutral* or *atmospheric line*), which represents the pressure of the atmosphere, the space enclosed above this line being the measure of the pressure above the atmospheric pressure, and below this line measuring the pressure below the atmosphere. If the junction between the indicator and the cylinder be now formed while steam is entering the cylinder, the indicator piston will evidently rise; and if steam be escaping from the cylinder, it will fall,—the extent of the rise and fall depending upon the strength of the spiral spring. The alternating circular motion of the roller is given by connecting it with any reciprocating part of the engine, by means of a cord attached to a pulley fixed on the same axis with the paper-roller. This

cord gives motion in one direction only, the return movement being communicated by a coiled spring attached to the instrument.

Scale.—The scale of the indicator in general use is divided into tenths of an inch, each division representing one pound pressure on the square inch of the piston. When the instrument is not in use, the index stands at 0; but when communication is opened with the engine, the pressure of steam is exhibited above zero, and the vacuum below.

*How to use the Indicator.**—To use the indicator, its cock must be made to fit the grease cock of the cylinder cover, or any other fitted for the purpose in a convenient place at the top or bottom of the cylinder, or both. The line may then be attached to the radius bar of the parallel motion at six or seven inches from the joint, and connected by a running loop to the hook on the small line at the bottom of the instrument. By means of the running loop, the line must be lengthened or shortened, till it is of the proper length to allow the roller to traverse as far as it can without coming into contact with the stop or the springs. This is easily effected by shifting the line upon the radius bar; and when the proper length has been found, the running loop may be fixed permanently, to be ready for future trials. Having stretched the paper upon the roller, and fastened it by means of the clasp, a sharp-pointed pencil is put into the socket, and allowed to press lightly (by means of a little spring) upon the surface of the paper. When all is ready, the instrument is first made to work a few strokes with the cock shut, in order to form the "atmospheric line," after which, the cock is opened when the piston is at the top of the stroke, and the registration proceeds as described.

How to make the Calculation.—When the figure is made,

* See p. 288, Marine Engines, new edition of Tredgold on the Steam Engine.

the pressure of the steam is calculated by drawing any number of lines across it at right angles to the atmospheric line, and taking their mean length, as measured on the scale attached to the instrument. In practice, it is usual to divide the figure into ten spaces by equidistant ordinates, measure each of those spaces in the middle, find their sum, and cut off a decimal figure for the division by 10, the result being the average force of the steam in pounds on the square inch. To find the power that the engine is actually exerting, therefore, we have only to take the area of the cylinder in square inches, multiply by the average pressure as found above, and again by the number of feet which the piston travels in a minute, when the product, divided by 33,000, is the indicator or gross horse-power of the engine.

To find the Nominal Horse Power of an Engine.—The horse power of an engine, as found in this way (which is the most accurate method with which engineers are acquainted), must not be confounded with what is called the *Nominal* or Commercial Horse Power. The latter is obtained by the following formula, viz. :—

$$\frac{\text{Area of cylinder} \times \text{effective pressure} \times \text{speed of piston}}{33{,}000} = \text{H. P.}$$

The area of the cylinder must be taken in square inches, the "effective pressure" assumed at 7 or 7½ lbs. per square inch of piston, and the speed is to be reckoned in the number of feet through which the piston travels, or *is expected* to travel, per minute. The divisor is 33,000 lbs. as before; this weight, when raised one foot high in a minute, being the standard of a commercial horse's power adopted by James Watt, and subsequently retained for convenience sake. In tendering for engines for the Government service, the "effective pressure" is assumed at seven pounds only, and the speed of the piston is presumed to vary with the length of stroke, according to the following table :—

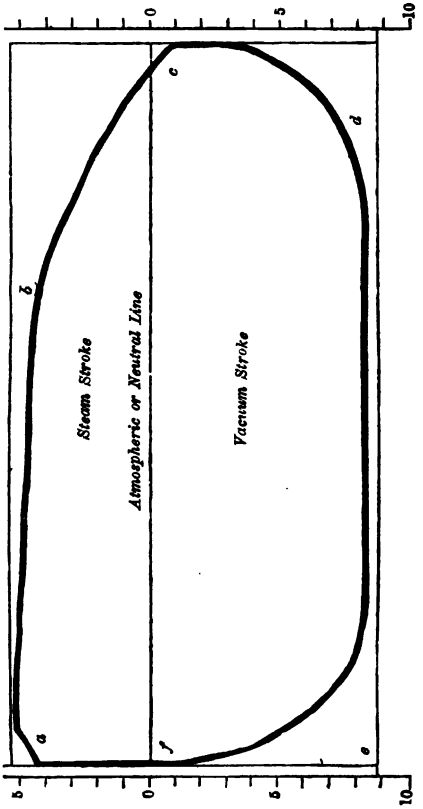
Stroke.		Speed of piston.	Stroke.		Speed of piston.
Ft.	In.	Ft. per min.	Ft.	In.	Ft. per min.
4	0	196	6	6	226
4	6	204	7	0	231
5	0	210	7	6	236
5	6	216	8	0	240
6	0	228			

We may observe, that on the Thames the effective pressure is usually taken at 7 lbs., and on the Clyde at $7\frac{1}{2}$ lbs., which tends to make the nominal horse-power of the Glasgow and Greenock engines of somewhat less commercial value than those built in London.

Distinction between Nominal and Real Horse-Power.—It will be seen that the horse power thus calculated is irrespective either of the actual pressure of the steam used, of the perfection of the vacuum in the condenser, or the amount of friction arising from good or bad workmanship; hence this rule, however useful in comparing the size of different engines, is a very imperfect guide to their actual power. We have thus two distinct values of horse power, which no one conversant with the steam engine ever confounds; the one, fixed and nominal, by which engines are bought and sold; the other fluctuating, though real, as shown by the indicator. To discover, however, *the effective power*, or the power actually available for the purpose for which the engine is used, a deduction would require to be made for friction of the moving parts and for the power required to work the pumps and valves, but as this would be nearly alike for well-constructed engines of equal power, and no ready means exists of testing it, the total or indicator horse power is taken as the measure of the power in all ordinary cases.

Use of the Indicator for showing the Internal State of the

Engine.—The indicator, moreover, tells us not merely the power exerted by the engine, but the nature of the faults (where those occur) by which the power is impaired. Thus, one form of the indicator figure, or "diagram," may show that the cylinder ports are too small, or that there is condensation in the steam pipes; another, that the engine is drawing air; or a third may show that the valves are improperly set. Let us take, for example, the accompanying imaginary diagram:—



When the pencil is at the point marked *a*, the piston is at

the commencement of its stroke, and the paper being made to move, the line is traced from *a* to *b*, and thence to *c*, at which point the stroke in one direction is finished. At the point *b* the valve is being shut, to prevent the further admission of steam; and while the line from *b* to *c* is being traced, the steam is expanding, and its pressure consequently decreasing, as indicated by the falling of the line. The line from *b* to *c*, instead of being convex, should be concave, as in the double diagrams, page 102; and it is thus discovered that the slide is in bad order, from steam being admitted after it is shut. If the engine had been working expansively, and the valve been shut before the pencil had reached the point *b*, the steam would have begun to expand at that point, and the line have begun to fall, so as to indicate the degree of expansion in the most precise and definite manner. On the pencil approaching the point *c*, the valve is opened to the condenser, the steam escapes, is condensed, the pressure falls, and the pencil descends towards *d*. The action as here indicated is not very good, as the corner should be more nearly square. The piston now commences its return stroke, and the paper is made to move simultaneously also in the opposite direction, and the line towards *e* is traced. It is here seen to rise again towards the atmospheric line, thus indicating that there is some pressure increasing in the cylinder. From the form of the diagram at this point, it is gathered that the vapour remaining enclosed in the cylinder, after the communication with the condenser has been closed, is compressed, and exerts a pressure against the piston to an injurious extent. As the pencil approaches *f*, the valve is opened for the admission of steam, and the pencil rises towards *a*, ready again to trace another diagram of what takes place on one side of the piston during another stroke.

To compare the Efficiency of different Engines by means of the Indicator.—The following method has been successfully adopted in comparing the relative economy of performance of different steam engines by means of their indicator diagrams.

First, calculate the gross indicator horse-power of the engine in the usual way, as already described. Then draw on the diagram a pure vacuum line at 15 lbs. below the atmospheric line; and if, as is generally the case, the eduction begins before the end of the stroke, continue upon the diagram the sloping line of the expansion as if it had been uniform to the end of the stroke, as represented, for instance, at *a*, *a*, Fig. p. 102.* The pressure of steam thus found at the end of the stroke (being the pressure above a pure vacuum) may be called the "Terminal" pressure.

Now find the cubic contents of the cylinder in feet, by multiplying the area into the length of stroke, and adding the "clearance" of piston at top or bottom, and the steam space in one port between the valve-face and the inside of the cylinder. The contents of the cylinder *at the terminal pressure* must now be reduced into the corresponding number of cubic feet of steam *at the atmospheric pressure*. This is easily done by reference to the table of relative volumes of steam pressure given in the Appendix. If our cylinder, for example, have 185 feet of cubic contents, and the terminal pressure be 8 lbs. above a vacuum, we must employ the following proportion:—

2983 (vol. corresponding to 8 lbs. pressure) : 185 :: 1669 (vol. corresponding to steam at atmospheric pressure) : 103·5 cub. ft. of steam at atmospheric pressure.

This amount being multiplied by the number of cylinders filled with steam in one minute, and the product being divided by the gross indicator horse-power as previously calculated from the diagram, we thus obtain the number of cubic feet of

* There is in general no difficulty in continuing this line with certainty, but if there be a doubt as to where the eduction begins, take the diagram at any definite point, say at nine-tenths of the stroke (after the valve has been certainly closed to all further admission of steam), and complete the figure by calculating, from the pressure of steam at this point, what would be its pressure if expanded into the increased space at the end of the stroke. This will be readily done by consulting the table of relative volumes of steam to pressure, given in the end of the book.

atmospheric steam required by this engine to produce one horse-power. It must not be forgotten that the cylinder of each engine is filled twice with steam for each revolution of the crank shaft.

The same simple process being gone through with the other engines under trial, or with the same engine under different circumstances of speed or expansion, affords a tolerably accurate method of comparing, in a general way, their relative efficiency.

Example of Calculation.—The following is the calculation made from the diagrams of *Penelope*, 650 nominal horse-power (Figs. p. 102).

The Diameter of cylinder is $91\frac{5}{8}$ in.
Area of ditto 6593·5 sq. in.=45·8 sq. ft.
Length of stroke 6 ft. 8 in., or with clearance, 6·75 ft.
No. of strokes per minute, 14.
Gross indicator horse-power for both engines, as per diagrams, 1333 H.-P.

Then, 45·8 area of cyl. in feet × 6·75 ft. length of stroke = 309·150 cub. ft. + 3·85 cub. ft. for steam space of port = 313 cub. ft. of steam required to fill the cylinder once, or 313 × 14 = 4382 cub. ft. of steam used above or below each piston in each cylinder during one minute.

Taking now from the diagrams the four terminal pressures corresponding to the top and bottom of each cylinder, we have,—

4382	cub. ft.	at 12	lbs.	press.	=3567	cub. ft.	at atmospheric press.
Do.	„	13	„	„	=3841	do.	„ „
Do.	„	15	„	„	=4382	do.	„ „
Do.	„	15	„	„	=4382	do.	„ „

16172 cubic feet of steam at atmospheric pressure used per minute by the two engines, or 16172 ÷ 1333 gross indicator horse-power = 12·13 cubic feet of atmospheric steam per horse-power per minute.

Difference of Effect between throttling the Steam and cutting it off by the Expansion Valve.—An experiment made in this manner to determine the difference of effect between expanding the steam in the cylinder by a proper system of expansion, and merely shutting it off by the throttle valve when it is wished to work the engines to a low power, gave the following result:—An engine of the nominal power of 400 horses was selected, and was first worked on the lowest grade of expansion, the steam in the boiler having its full pressure of 8 lbs. Under these circumstances, it was found that 10·87 cubic feet of steam at atmospheric pressure were consumed per horse-power per minute.

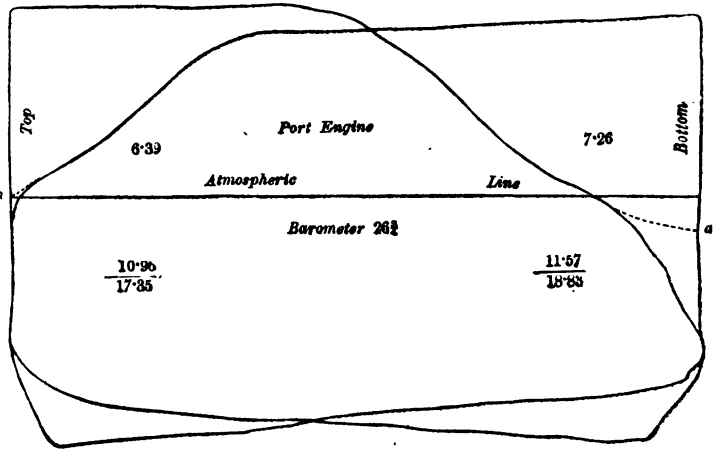
The expansion valves were then thrown out of gear, and the engines reduced by the throttle valve to exactly the same number of revolutions. It was now found that although the gross horse-power, as shown by the indicator, was almost identical in both cases, in the latter case the power exerted was obtained at an expenditure of 14·72 cubic feet of atmospheric steam per minute, in place of 10·87 cubic feet, as formerly; 3·85 cubic feet of steam per indicated horse-power per minute being thus saved by the principle of expansion.

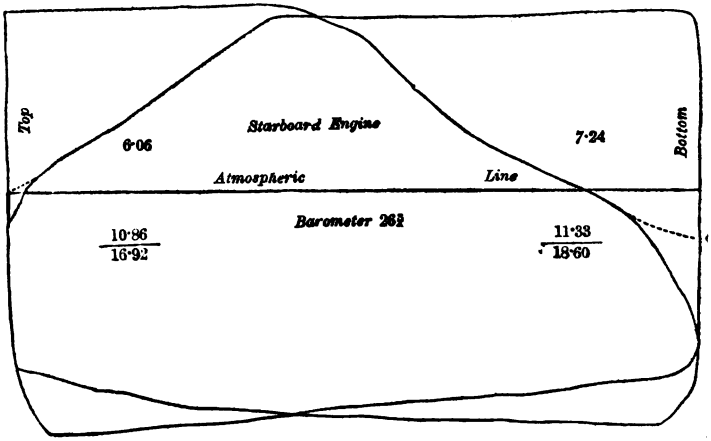
It is apparent that this calculation will not give us the *cause* of any loss of effect by the steam escaping, or being condensed in the pipes, etc., which must be sought for when suspected, either in the form of the indicator diagram, or by testing the engine for leakage of steam or air.

Dynamometer.—A DYNAMOMETER is an instrument by which it is attempted to measure the force actually exerted in propelling a vessel. An excellent one, designed by Mr. Colladon of Geneva, has been erected in Woolwich Dockyard, by which the pull of any vessel made fast to it can be accurately measured. An instrument of this kind, but subject to many disturbing influences, can be fitted on board screw steamers, to show the thrust of the propeller shaft through a series of levers on a spring balance. The lever is sometimes

INDICATOR DIAGRAM FROM *PENELOPE'S* ENGINES.

FULL STEAM, 14 REVOLUTIONS, 650 NOMINAL H.-P.





Starboard Cyl. Top 16·92, Bott. 18·60 } Mean 17·76
Port Cyl . . Top 17·35, Bott. 18·83 } Mean 18·09
} Mean 17·92

$$\frac{6593{\cdot}5 \times 186{\cdot}2 \times 17{\cdot}92}{33{,}000} = 666{\cdot}6 \times 2 = 1333 \text{ H.-P.}$$

exerted by both engines.

made to take the pressure from the end of the shaft; at other times, from a revolving frame with a number of friction rollers in it, which works against a collar on the shaft at any part that may be most convenient. The lever or levers should have knife-edge centres, so as to work with as little friction as possible; and the rod connecting the lever with the spring balance has a small sliding rod attached to it, carrying a pencil. By the side of this rod is a small cylinder, round which a piece of paper is coiled, as in the indicator. This cylinder receives a continuous rotatory motion by means of a small band from the screw shaft, the motion being so regulated that the speed of the cylinder (round which the paper is coiled) may be considerably less than that of the screw shaft. The pencil is now brought into contact with the paper on the cylinder, and a zero line traced before the pressure of the shaft is allowed to act upon the lever. The pencil should now be disengaged from the paper, and the connecting rod of the lever screwed up until it is ascertained that the whole forward pressure of the shaft acts upon the lever, and that the shaft is quite clear of every other part of the machinery which might receive a portion of the pressure. Upon the pencil being again brought into contact with the paper, an undulating line is described upon it, showing the variable thrust of the engines upon the propeller during the period of each revolution. After the diagram is traced, the paper is taken off, and equidistant lines drawn at right angles to the zero line, the lengths of these ordinates from the curve to the zero line, measured upon the scale of pounds of the spring balance, giving the action of the lever upon the balance at these places. The numbers being then marked upon the diagram, their sum taken, and divided by the number of ordinates for a mean, we shall have the force exerted on the lever, which, being multiplied by the leverage, will give the average forward pressure exerted by the propeller shaft upon the vessel. If it be only a single lever that is used for the dynamometer, the leverage is of course found by dividing the length from the fulcrum to the point where

the rod of the spring balance is attached, by the length between the fulcrum and the point which receives the pressure of the shaft; but if it is a compound lever that is used, multiply together all the long arms of the levers, and divide the product by the product of all the short arms (measuring the length from the fulcrum of each lever), and the quotient is the leverage. When the forward pull or pressure in pounds has been found, the number of horses' power may be calculated for paddle-wheel vessels attached to Mr. Colladon's machine, by multiplying the velocity of the centre of effort of the paddle-board in feet per minute, by the total pull in pounds, and dividing the product by 33,000. The centre of effort of a paddle-board may be taken at one-third of its depth from the outer edge. In screw vessels, the speed of the screw must be taken for the velocity. Experiments with this instrument, when worked out in this way, have generally shown the effective to be about one-half the gross indicator horse-power.

Counter.—The COUNTER is an instrument so contrived by the aid of wheelwork that an index hand is moved forward a certain distance for every stroke of the engine, thus registering or "counting" the number of strokes an engine makes during a day, a month, or any given period. The construction of the counter varies much; in most cases, however, the wheels are moved round by a pendulum attached to some vibrating part of the engine, the wheel being carried forward one tooth for every vibration, and an extreme slowness being obtained by a differential motion. In many steamers, as for instance in those of the Royal Mail Company, the number of strokes of the engines, as shown on the dial-plate of the counter, is used as a means of verifying the rate of the vessel as obtained in the usual way by log and solar observations, the progression of the wheels or screw, minus the slip, giving the rate of the ship, and a deduction being made for the currents when these are known.

ENGINEER'S LOG OF THE ROYAL MAIL STEAM PACKET COMPANY'S STEAM SHIP *ATRATO* (PADDLE WHEEL), FROM SOUTHAMPTON TO ST. THOMAS. SECOND RUN, COMMENCING 17TH MAY, 1854.

	Revolutions of Engines.		Knots per day.		Coals consumed per day.		Steam gauge.	Full Steam.	Expansion grades per day.				Remarks on the draught of water, the weather, sails set, etc.
Dates.	Day of 24 hrs.	Per min.	Wheel.	Ship.	Ton.	Cwt.	lbs.		1	2	3	4	Draught of water at Starting, Forward 20 ft. 5 in., Aft 20 ft. 11 in.
May 18	19183	15·0	303	266	88	4	17	Full	....	..	..	..	Start from Southampton at 2.30 p.m., no wind.
19	21794	15·1	363	303	96	8	16¾	Full	....	..	..	..	Wind on beam, plain sail set; 1 a.m., no wind.
20	22249	15·4	370	310	98	10	16¾	12 h.	12 h.	..	..	..	Smooth water, no wind.
21	22869	15·9	381	321	100	7	16¾	....	„	..	..	..	Smooth water, no wind to retard engines.
22	22511	15·7	375	309	107	9	17¼	....	„	„	..	..	Engines on 1st and 2nd grades, ship rolling; wind light.
23	23814	16·6	397	337	104	8	17½	....	„	„	..	..	Smooth water, fore and aft sail set. [engines.
24	23302	16·1	388	310	104	13	17½	....	„	„	..	..	Noon, in all sail, wind head; chopping sea retarding
25	23760	16·5	396	325	107	19	17¼	....	„	„	..	..	No wind, smooth water.
26	24444	17·0	407	332	112	1	17½	....	„	„	..	..	Smooth water, no wind.
27	24436	17·0	407	332	106	18	17¼	....	....	„	..	..	Smooth water, no wind; engines on second grade.
28	25080	17·4	418	343	105	14	17½	....	....	„	..	..	Wind before the beam, fore and aft sail set for 12 hours.
29	12188	17·2	203	163	49	12	17½	....	....	„	..	..	No wind, stop off the harbour of St. Thomas at 11.30 p.m.
				3651	1182	3							Draught of water on arrival, Forward 16 ft. 3 in., Aft 16 ft. 10 in.

Length of run, 12 days 9 hours. Average speed of ship, 12·28 knots per hour. Average slip of wheels (feathering), 17 per cent. Total consumption of coals, 1182·15 tons, or 95·33 tons per day.

JAMES WILKIE,
Chief Engineer.

ENGINEER'S LOG OF THE ROYAL MAIL STEAM PACKET COMPANY'S STEAM SHIP *ATRATO* (PADDLE WHEEL), FROM SOUTHAMPTON TO ST. THOMAS. SEVENTEENTH RUN, COMMENCING 2ND MARCH, 1857.

	Revolutions of Engines.		Knots per day.		Coals consumed per day.		Steam gauge.	Full Steam.	Expansion grades per day.				Remarks on the draught of water, the weather, sails set, etc.
Dates.	Day.	Per min.	Wheel.	Ship.	Ton.	Cwt.	lbs.		1	2	3	4	Draught of water, Forward 20 ft. 9 in., Aft 21 ft. 2 in.
Mar. 3	18574	14·1	309	244	90	....	16	Full.	....	..	..	..	Start from Southampton at 2.47 p.m., smooth water.
4	20126	14·0	335	268	94	4	16	Full.	„	..	..	..	Smooth water, heavy swell, no wind, ship rolling.
5	21300	14·8	355	284	96	18	16	....	„	„	..	..	Smooth water, no wind, ship rolling.
6	21500	14·9	358	287	96	3	16	....	12 h.	„	..	..	No wind, ship rolling deep.
7	21300	14·8	356	284	95	12	16	....	....	„	..	..	Wind beam, ship rolling, heavy swell.
8	21978	15·2	366	292	98	17	16	....	....	„	..	..	No wind, ship rolling.
9	21922	15·2	365	292	97	16	16	....	....	„	..	..	No wind, confused sea, ship rolling and pitching.
10	22600	16·3	376	294	96	....	16	....	....	„	..	..	No wind, engines stopped 50 min., a man overboard.
11	23640	16·4	394	327	102	10	16½	....	....	„	..	..	Wind beam very light, sail set a part of the day.
12	23960	16·7	399	327	102	3	16½	....	....	„	..	..	Wind beam, all plain sails set, ship rolling, beam swell.
13	23650	16·4	394	322	100	19	16½	....	....	„	..	..	Wind quarterly, ship rolling deep and often, plain sail set.
14	23690	16·4	395	323	101	3	16½	....	....	„	..	..	Wind quarterly, ship rolling deep, no sail to assist engines.
15	10140	16·3	169	140	39	....	16	....	....	„	..	..	Slowed engines at 10.10 p.m., stopped in the harbour of St. Thomas at 10.20. Draught of water, forward 16 ft. 3 in., aft 16 ft. 9 in.
				3684	1211	5							

Length of run, 13 days 7 hours 33 minutes. Average speed of ship, 11·53 knots per hour. Average slip of wheels (feathering), 18 per cent. Total consumption of coals, 1211·25 tons, or 91·75 tons per day.

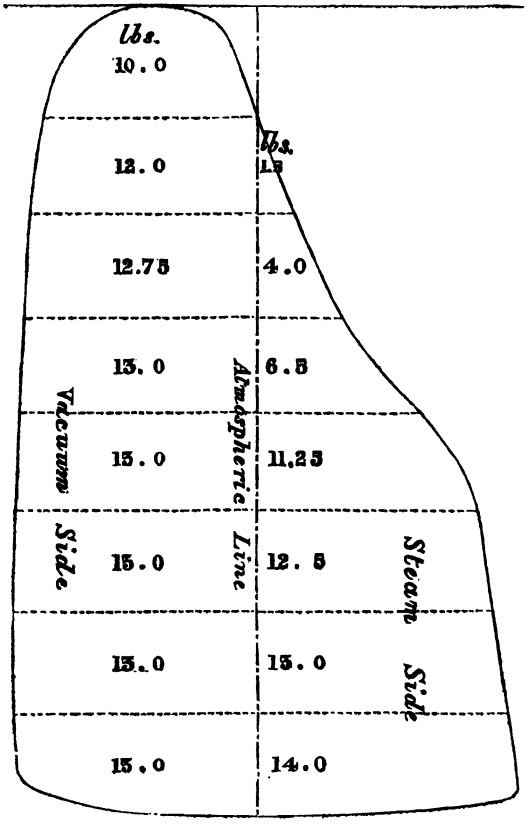
JAMES WILKIE,
Chief Engineer.

INDICATOR DIAGRAM OF *ATRATO*, JANUARY 22ND, 1857,

Taken from starboard engine, above the piston.

Pressure of steam in the boilers, 16 lbs.
Amount of expansion, second grade.
Vacuum in the condensers, 25¾ inches.
Revolutions per minute, 14·2.
Consumption of Risca Black vein coal, 78 cwt. per hour.
Wind before the beam, with confused sea.

JAMES WILKIE, Chief Engineer.



Average, 12·4 lbs. | 9 lbs. Average.

ENGINEER'S LOG OF THE PENINSULAR AND ORIENTAL STEAM NAVIGATION COMPANY'S SCREW STEAM SHIP *PERA*. THE SEVENTH ALEXANDRIAN VOYAGE, APRIL 8TH, 1857.

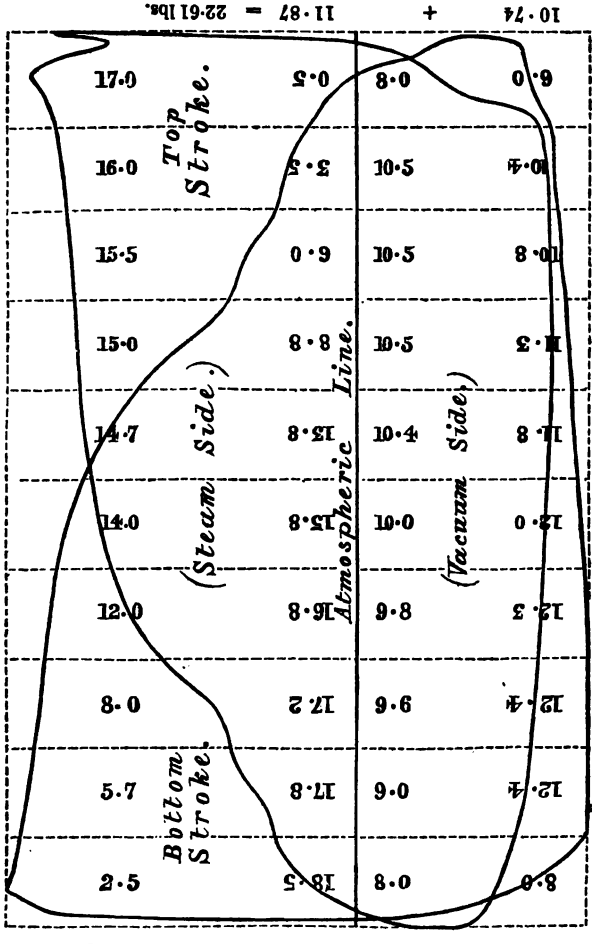
Watch.	Pressure of Steam.	Grade of Expansion.	No. of Strokes per minute per watch.	Vacuum.	Height of Water in Boilers.	Density of Water.	Number of Boilers at work.	Tempera-ture of Condensers.	Tempera-ture of En. Room.
3rd. 1 A.M.	15 lbs.	1st.	30½	25	9	17	4	120°	100°
4th.* 5 A.M.	15 lbs.	1st.	31	25	9	17	4	120	100
2nd. 9 A.M.	15 lbs.	1st.	31	25	9	17	4	120	100
3rd. 1 P.M.	15 lbs.	1st.	31	25	9	17	4	120	100
4th. 5 P.M.	15 lbs.	1st.	30½	25	9	16	4	120	100
2nd.† 9 P.M.	15 lbs.	1st.	30½	25	9	16	4	120	100
12	15 lbs.	1st.	30½	25	9	16	4	120	100

Consumption of coals, fifty tons in twenty-four hours. Coals dirty, clearing three fires every watch.

* At 6.30 A.M. set fore and aft sails; wind off starboard bow. † In all sails at 10.30 P.M.; head-wind.

INDICATOR DIAGRAM FROM FORWARD ENGINE OF THE *PERA*.

32½ REVOLUTIONS PER MINUTE, 1130 INDIC. H.-P.



12·04 + 9·63 = 21·67 lbs. Top.
22·61 lbs. Bottom.
Mean 22·14 lbs.

steam." "Also, the increased effect of the combined steam was 25 per cent. above that obtained from the surcharged steam alone."

The second set of American experiments were made with the steamboat *Joseph Johnson*, in the Hudson River at New York. This is a towing vessel with one engine, the cylinder being 31½ in. diameter and 6 ft. 9 in. stroke, the steam being cut off at five-eighths of the stroke from the commencement. It had a single iron boiler "with the furnace and direct flues below, and single return ascending flues above. A steam chimney surrounded the smoke chimney, and the average temperature of the latter was 600° Fahr."

"The steam was surcharged by taking it from the steam chimney inside the smoke chimney, leading it down the latter, then through the upper flues, then returning through the lower direct flues, whence it was led to the supply-pipe, and there mixed with saturated (common) steam brought by a pipe, externally to the boiler, from the same steam chimney."

Summary of the results obtained from the experiments with the *Joseph Johnson*, made January 5th and 9th:—

Experiments made January 5th and 9th.	With Common Steam alone.	With Combined Steam.
Duration of the experiments, in hours and minutes	9 h. 53 m.	9 h. 50 m.
Steam pressure in boiler, in lbs. per square inch	19·5 lbs.	18·5 lbs.
Vacuum in condenser in inches of mercury	27·5 in.	27·8 in.
Mean temperature of metal of cylinder	231·1°	289·2°
Temperature of the exhaust	125.0°	147·6°
Temperature of surcharged steam	.....	577·1°
Temperature of combined steam	.....	350·7°
Total number of double strokes of piston made during the experiments	11,447	11,904
Number of double strokes of piston per minute	19·303	20·176
Pounds of anthracite coal consumed per hour	666·66 lbs.	440·82 lbs.

"Whence it appears, taking into account the number of strokes made and the fuel consumed, that the economical efficiency of the combined steam is 72·694 per cent. greater than that of the common steam alone."

Other experiments were then subsequently made with the same vessel, in order to judge of the economy of the system, when the revolutions of the paddle wheels and the speed of the vessel were kept the same in each case.

The following therefore is the summary of the results obtained from the experiments made November 22nd and 23rd:—

Experiments made November 22nd and 23rd.	With Common Steam alone	With Combined Steam.
Duration of the experiments in hours and minutes	4 h. 32 m.	4 h. 30 m.
Steam pressure in boiler, in lbs. per square inch	22·55 lbs.	18·94 lbs.
Temperature of steam in steam pipe near boiler	247·7°	
Temperature of steam in valve chest of cylinder	195·0°	
Temperature of surcharged steam, before mixing	.....	578·3°
Temperature of combined steam in valve chest	.....	333·4°
Temperature of the exhaust	133·6°	
Number of double strokes of engine, by counter	5536	5455
Number ditto per minute	20·35	20·20
Total pounds of anthracite coal consumed	2055 lbs.	1300 lbs.
Pounds of coal consumed per hour	453·3 lbs.	288·9 lbs.

"Whence it appears that the economical efficiency of the combined steam is 33·51 per cent. greater than that of the common steam alone."

The fact of the percentage of gain being less in these last experiments than in the former ones, is explained by the statement, that in order to keep the engine-power, when using

the combined steam, down to the same standard as when using common steam alone, it was necessary to carry the fires so low that they burnt into holes on the bars, and cooled the flues.

The French experiments gave the following results:—

French Experiments.	Common Steam alone.	Superheated Steam alone.	Combined Steam.
Average pressure in boiler	2·0 atmos.	2·4 atmos.	2·35 atmos.
Temperature in chamber.	128° Réau.	160° Réau.	257° Réau.
Strokes of piston in 4 hrs.	7892	7886	7866
Coal consumed in 4 hrs.	151 kilos.	98·8 kilos.	72 kilos.
Revolutions	19·2	12·5	9·1

The experiment with superheated steam alone was conducted so as to produce (sensibly) the same number of revolutions as the first. In the two first experiments the valves were wide open, and in the last, with the combined steam, they were partially closed.

The following are the conclusions from these experiments, arrived at by the French Commission:—

"1st. The use of superheated steam, compared with ordinary steam, reduces the expense of fuel from 19·2 to 12·5, —that is to say, in the proportion of 100 to 65·1.

"2nd. The use of superheated steam, mixed with ordinary steam, compared with superheated steam alone, reduces the expense of fuel from 12·5 to 9·1,—that is to say, in the proportion of 100 to 76·8; and compared with the use of ordinary steam alone, gives a profit of 52·7 for 100."

In the beginning of the year 1856, the Admiralty yacht *Black Eagle* was fitted with Mr. Wethered's apparatus, and a few months later H. M. steam troop-ship *Dee*. The arrangement adopted in the *Dee* for superheating the steam, consists of iron pipes carried from the steam pipe along the front of the tube plate, and extending into the up-take or chimney, where they are coiled, to increase the heating surface. These pipes rejoin the steam pipes near the cylinders, where the temperature of the combined steam (in the *Dee*) is about

300°, the temperature in the superheated steam alone being nearly 500°.

By consulting the Tables of the Woolwich experiments,* it will be seen that Mr. Atherton gives, for the *Black Eagle*, 18 per cent. economy of fuel in favour of the combined steam, and for the *Dee*, 31 per cent. Although these percentages are not so high as those deduced from either the American or the French experiments, they abundantly show the very great importance of this subject, provided the actual gain can be thoroughly substantiated. It necessarily follows, from the very nature of the process, that the worse the boiler on which it is tried, the greater will be the apparent economy attending it, since the increased power is evidently obtained from the vaporization of the watery particles held in suspension by *wet steam* (along with the superheating of the whole steam), the necessary heat required to effect this being derived from the *waste heat* escaping up the chimney. It need scarcely be remarked that in a well constructed marine boiler the steam leaves it in a comparatively dry state, and that the temperature in the up-take is so low as scarcely to afford scope for the superheating process; although there are doubtless multitudes of boilers in which these conditions are not present. Should it only prove a ready means of improving the steaming qualities of a bad boiler, there seems no reason why it should not become extensively useful, the expense attending its application being moderate,—but at the same time we should prefer a boiler which gave off its steam dry in the first instance, and which had no waste heat to spare for cooking it afterwards. Unless we can be assured that the particular boiler which has been made the subject of experiment with Wethered's Apparatus is in all respects a good and efficient one according to our present ideas of perfection in a marine boiler, the seeming economy resulting from the process will be more apparent than real.

* Pages 116, 117.

TRIALS OF WETHERED'S SYSTEM OF SUPERHEATED STEAM AS COMPARED WITH ORDINARY STEAM, IN H. M. STEAMER *BLACK EAGLE*.

	Date of Trial.	Area of the two Superheating Pipes.	Area of the Passage for Plain Steam in passing the Stop Valves.	Time occupied.	Draught of Water, Forward.	Draught of water, Aft.	Average Height of Steam Gauge.	Average Revolutions per minute.	Average Vacuum per Indicator.	Average Pressure on Pistons.	Indicated Horse-power.	Coals consumed per hour.	Coals consumed per indicated Horse-power.	Temperature of Steam in Boilers.	Temperature of Superheated Steam.	Temperature of Plain Steam at Throttle Valves.	Temperature of the Combined Steam.	Temperature of the Exhaust Steam.	Barometer on the Condenser.	Speed of Vessel, by Patent Log.
	1855.	Sq. in.	Sq. in.	Hrs.	Ft. in.	Ft. in.	In.		lbs. sq. in.	lbs. sq. in.		lbs.	lbs.						In.	Knots per hour.
Plain.	Oct. 4	0	127	9	.....	.....	8·75	21·58	11·315	15·91	569·4	3752	6·59	.....	.....	239·9	.....	123°	25·5	9·68
,,	5	0	127	8¼	.....	.....	8·75	22·7	11·175	15·56	585·8	3770	6·44	.....	.....	242	.....	126°	25·5	9·63
,,	6	0	127	10	.....	.....	6·71	22.58	11·245	14·02	525·0	3528	6·72	.....	.....	236	.....	123°	25·5	9·99
	1856.																			
Superheated.	Feb.18*	15·32	Variable.	6	11·3	11·8	8·9	21·67	11·47	13·47	484·1	2865	5·92	229·1	436·5	.....	252·8	112°	25·5	9·51
,,	19*	Variable.	,,	9	10·11	11·7	11·0	21·74	10·965	13·38	482·4	2682	5·56	232·7	441·5	.....	277·0	114°	25·5	9·77
Plain.	20*	0	,,	5	10·9	11·6	10·47	22·14	11·56	13·28	487·6	3024	6·2	230†	.....	234†	.....	.....	25·5	9·67
Superheated.	21‡	15·32	31·8	5	10·8	11·5	10·42	22·52	11·405	13·764	513·9	2408	4·69	230	501·5	.....	254·5	114°	25·5	9·82
Plain.	22‡	0	127	8	10·7	11·3	10·0	23·36	11·07	14·611	566·1	3262	5·76	230	.....	238	.....	112°	25·5	10·29

* These three days were devoted to ascertaining the proportion of plain to superheated steam at which the engines work to best advantage.

† This apparent discrepancy was caused by the superheating pipe being in connection with the main steam pipe, notwithstanding that the steam was shut off between the boiler and the superheating steam pipe, while using plain steam.

‡ Test trials. These comparative trials show 18 per cent. economy of fuel in favour of the superheated steam.

	Sectional Area of Superheating Pipes.	Area of Passage for Plain Steam in passing the Stop Valves.	Area of Feed in inches open.	Area of Injection in inches open.	Draught of Water, Forward.	Draught of Water, Aft.	Time occupied in Experiment.	Average Height of Steam Gauge.	Average Revolutions by Counter.	Average Vacuum by Indicator.	Average Pressure on Pistons.	Indicated Horse-power.	Coal Consumed per Hour.	Coal Consumed per Indicated Horse-power.	Temperature of Steam in the Boilers.	Temperature of Superheated Steam.	Temperature of Plain Steam in Cylinders.	Temperature of the Combined Steam.	Temperature of the Exhaust.	Temperature of the Engine Room.	Barometer on Condensers.	Speed of the Vessel.
	In.	In.	In.	In.	Ft. In.	Ft. In.	Hrs.	In.	Pr. Min.	lbs. sq. in.	lbs. sq in.		lbs.	lbs.	Degs.	Degs.	Degs.	Degs.	Degs.	Degs.	In.	Knots
First Voyage.																						
Plain Steam .	....	full open	2½	full 4	14·6	14·3	17	9	16·63	12·59	18·11	410·2	2205	5·4	233	.....	232	.....	113	87	$26\frac{2}{10}$	7
Superheated .	31·8	30	2½	3	14·6	14·3	17	9·3	16·95	12·75	18·23	421·2	1569	3·75	230	494	.....	307	110	87	$26\frac{3}{10}$	7·2
Second Voyage.																						
Plain Steam .	....	full open	2½	4	13·0	12·9	9	7·6	23·53	12·12	16·06	514·3	2356	4·58	224	.....	235	.....	111	78	$25\frac{2}{4}$	7·8
Superheated .	31·8	30	2½	3	13·0	12·9	9	8	24·58	12·23	16·85	563·6	1778	3·15	224	493	.....	318	$114\frac{1}{2}$	80	$26\frac{2}{4}$	8
Third Voyage.																						
Plain Steam .	....	full open	2½	4	12·10	12·7	18	6·3	23·58	12·05	15·05	482·1	2533	5·25	231	.....	229	.....	121	87	$26\frac{1}{4}$	7·9
Superheated .	31·8	$9\frac{1}{6}$	2½	3	12·10	12·7	18	6	23·79	12·27	15·59	503·8	1756	3·119	$230\frac{1}{2}$	432	.....	318	$113\frac{1}{2}$	92	$26\frac{2}{4}$	8
Fourth Voyage.																						
Plain Steam .	....	full open	2½	$6\frac{1}{2}$	13·2	13·2	2	7·5	24·0	11·96	16·55	539·6	2950	5·47	232	.....	230	.....	125	.....	26	8·2
Superheated .	31·8	35	2½	5	13·2	13·2	2	10·25	25·85	11·82	17·68	621	2100	3·38	237	465	.....	292	130	.....	26	8·4

The first trial was made from Woolwich to Plymouth, on the 26th, 27th, and 28th of July, 1856. Deep draught, loaded with machinery. Speed of the piston per min. 167·8 ft. Immersion of floats 4 feet 10 in. 30·6 per cent. economy in favour of superheated steam.

The second voyage was from Plymouth to Pembroke, and took place on the 2nd and 3rd of August. Trial light. Speed of the piston 240.6 ft. per min. Immersion of floats 3 ft. 6 in. 31·2 per cent. economy in favour of superheated steam.

The third voyage, from Pembroke to Sheerness, was made on the 4th, 5th, and 6th of August. Trial light. Speed of the piston 236·8 ft. per min. Immersion of floats 3 ft. 3 in. The coal used in this trial was very small and dirty, which accounts for the coal used per indicated horse-power being higher than that in the second trial. 33·5 per cent. economy in favour of superheated steam.

The fourth trial, on the 19th of August, was made at the "Lower Hope." Comparative economy in favour of superheated steam, 38·2 per cent. Immersion of floats 3 ft. 10 in. 3·38 lbs. of coal per indicated horse-power consumed in this trial may be considered an equivalent to the 3·15 lbs. of coal consumed in the second trial, on account of the increased consumption of coal per horse-power which is necessary to produce the greater power; which shows that the second trial gives the maximum economical effect for plain steam. The 38·2 per cent. saving is not altogether due to the superheating pipes; but the excess, as compared with the second trial, is due to the boiler having been worked in the fourth trial above its maximum economical rate for plain steam.

The description of Coal used was, for the first voyage, West Hartley, and for the other three voyages West Hartley and Welsh mixed.

CHARLES ATHERTON.

TRIALS OF WETHERED'S SYSTEM OF SUPERHEATED STEAM AS COMPARED WITH ORDINARY STEAM, IN H. M. STEAMER *BLACK EAGLE*.

	Date of Trial.	Area of the two Superheating Pipes.	Area of the Passage for Plain Steam in passing the Stop Valves.	Time occupied.	Draught of Water, Forward.	Draught of water, Aft.	Average Height of Steam Gauge.	Average Revolutions per minute.	Average Vacuum per Indicator.	Average Pressure on Pistons.	Indicated Horse-power.	Coals consumed per hour.	Coals consumed per indicated Horse-power.	Temperature of Steam in Boilers.	Temperature of Superheated Steam.	Temperature of Plain Steam at Throttle Valves.	Temperature of the Combined Steam.	Temperature of the Exhaust Steam.	Barometer on the Condenser.	Speed of Vessel, by Patent Log.
	1855.	Sq. in.	Sq. in.	Hrs.	Ft. in.	Ft. in.	In.		lbs. sq. in.	lbs. sq. in.		lbs.	lbs.						In.	Knots per hour.
Plain.	Oct. 4	0	127	9	.....	.....	8·75	21·58	11·315	15·91	569·4	3752	6·59	.....	.....	239·9	.....	123°	25·5	9·68
,,	5	0	127	8¼	.....	.....	8·75	22·7	11·175	15·56	585·8	3770	6·44	.....	.....	242	.....	126°	25·5	9·63
,,	6	0	127	10	.....	.....	6·71	22.58	11·245	14·02	525·0	3528	6·72	.....	.....	236	.....	123°	25·5	9·99
	1856.																			
Superheated.	Feb. 18*	15·32	Variable.	6	11·3	11·8	8·9	21·67	11·47	13·47	484·1	2865	5·92	229·1	436·5	.....	252·8	112°	25·5	9·51
,,	19*	Variable.	,,	9	10·11	11·7	11·0	21·74	10·965	13·38	482·4	2682	5·56	232·7	441·5	.....	277·0	114°	25·5	9·77
Plain.	20*	0	,,	5	10·9	11·6	10·47	22·14	11·56	13·28	487·6	3024	6·2	230†	.....	234†	.....	.....	25·5	9·67
Superheated.	21‡	15·32	31·8	5	10·8	11·5	10·42	22·52	11·405	13·764	513·9	2408	4·69	230	501·5	.....	254·5	114°	25·5	9·82
Plain.	22‡	0	127	8	10·7	11·3	10·0	23·36	11·07	14·611	566·1	3262	5·76	230	.....	238	.....	112°	25·5	10·29

* These three days were devoted to ascertaining the proportion of plain to superheated steam at which the engines work to best advantage.

† This apparent discrepancy was caused by the superheating pipe being in connection with the main steam pipe, notwithstanding that the steam was shut off between the boiler and the superheating steam pipe, while using plain steam.

‡ Test trials. These comparative trials show 18 per cent. economy of fuel in favour of the superheated steam.

	Sectional Area of Superheating Pipes.	Area of Passage for Plain Steam in passing the Stop Valves.	Area of Feed in inches open.	Area of Injection in inches open.	Draught of Water, Forward.	Draught of Water, Aft.	Time occupied in Experiment.	Average Height of Steam Gauge.	Average Revolutions by Counter.	Average Vacuum by Indicator.	Average Pressure on Pistons.	Indicated Horse-power.	Coal Consumed per Hour.	Coal Consumed per Indicated Horse-power.	Temperature of Steam in the Boilers.	Temperature of Superheated Steam.	Temperature of Plain Steam in Cylinders.	Temperature of the Combined Steam.	Temperature of the Exhaust.	Temperature of the Engine Room.	Barometer on Condensers.	Speed of the Vessel.
	In.	In.	In.	In.	Ft. In.	Ft. In.	Hrs.	In.	Pr. Min.	lbs. sq. in.	lbs. sq in.		lbs.	lbs.	Degs.	Degs.	Degs.	Degs.	Degs.	Degs.	In.	Knots
First Voyage.																						
Plain Steam .	....	full open	$\frac{3}{4}$	full	4 14·6	14·3	17	9	16·63	12·59	18·11	410·2	2205	5·4	233	.....	232	.....	113	87	$26\frac{7}{8}$	7
Superheated .	31·8	30	$\frac{3}{4}$	3	14·6	14·3	17	9·3	16·95	12·75	18·23	421·2	1569	3·75	230	494	.....	307	110	87	$26\frac{8}{10}$	7·2
Second Voyage.																						
Plain Steam .	....	full open	$\frac{3}{4}$	4	13·0	12·9	9	7·6	23·53	12·12	16·06	514·3	2356	4·58	224	.....	235	.....	111	78	$25\frac{9}{10}$	7·8
Superheated .	31·8	30	$\frac{3}{4}$	3	13·0	12·9	9	8	24·58	12·23	16·85	563·6	1778	3·15	224	493	.....	318	$114\frac{1}{2}$	80	$26\frac{2}{10}$	8
Third Voyage.																						
Plain Steam .	....	full open	$\frac{3}{4}$	4	12·10	12·7	18	6·3	23·58	12·05	15·05	482·1	2533	5·25	231	.....	229	.....	121	87	$26\frac{1}{2}$	7·9
Superheated .	31·8	$9\frac{1}{2}$	$\frac{3}{4}$	3	12·10	12·7	18	6	23·79	12·27	15·59	503·8	1756	3·119	$230\frac{1}{2}$	432	.....	318	$113\frac{1}{2}$	92	$26\frac{2}{10}$	8
Fourth Voyage.																						
Plain Steam .	....	full open	$\frac{3}{4}$	$6\frac{1}{2}$	13·2	13·2	2	7·5	24·0	11·96	16·55	539·6	2950	5·47	232	.....	230	.....	125	.....	26	8·2
Superheated .	31·8	35	$\frac{3}{4}$	5	13·2	13·2	2	10·25	25·85	11·82	17·68	621	2100	3·38	237	465	.....	292	130	.....	26	8·4

The first trial was made from Woolwich to Plymouth, on the 26th, 27th, and 28th of July, 1856. Deep draught, loaded with machinery. Speed of the piston per min. 167·8 ft. Immersion of floats 4 feet 10 in. 30·6 per cent. economy in favour of superheated steam.

The second voyage was from Plymouth to Pembroke, and took place on the 2nd and 3rd of August. Trial light. Speed of the piston 240.6 ft. per min. Immersion of floats 3 ft. 6 in. 31·2 per cent. economy in favour of superheated steam.

The third voyage, from Pembroke to Sheerness, was made on the 4th, 5th, and 6th of August. Trial light. Speed of the piston 236·8 ft. per min. Immersion of floats 3 ft. 3 in. The coal used in this trial was very small and dirty, which accounts for the coal used per indicated horse-power being higher than that in the second trial. 33·5 per cent. economy in favour of superheated steam.

The fourth trial, on the 19th of August, was made at the "Lower Hope." Comparative economy in favour of superheated steam, 38·2 per cent. Immersion of floats 3 ft. 10 in. 3·38 lbs. of coal per indicated horse-power consumed in this trial may be considered an equivalent to the 3·15 lbs. of coal consumed in the second trial, on account of the increased consumption of coal per horse-power which is necessary to produce the greater power; which shows that the second trial gives the maximum economical effect for plain steam. The 38·2 per cent. saving is not altogether due to the superheating pipes; but the excess, as compared with the second trial, is due to the boiler having been worked in the fourth trial above its maximum economical rate for plain steam.

The description of Coal used was, for the first voyage, West Hartley, and for the other three voyages West Hartley and Welsh mixed.

CHARLES ATHERTON.

CHAPTER X.

ON THE QUALITIES OF FUEL, WITH HINTS FOR ITS SELECTION.

On the Qualities and Value of Different Coals.—The following observations upon the qualities and economic values of coal from different localities, are condensed chiefly from the Parliamentary "Report on Coals suited to the Royal Navy," drawn up in the years 1848–49, by Sir Henry de la Beche and Dr. Lyon Playfair.

Much depends on the Construction of the Boiler.—In estimating the evaporative power of coals, much must of course depend upon the construction of the boiler, and the manner in which the fuel is burnt on the grate. Thus, in Cornwall, where every attainable advantage is given to the fuel by large heating surface, slow combustion, and prevention of loss of heat by radiation, the average evaporative value of 1 lb. of coals may be taken at 10 to 11 lbs. of water, while in marine tubular boilers it rarely exceeds 8 to 8½ lbs. An evaporative power of 14 lbs. of water is the highest result *theoretically* possible for a good average sample of coal.

Mr. Wicksteed's Experiments.—Mr. Wicksteed's experiments on this subject give the following results in pounds of water evaporated by one pound of coal, in land boilers of good construction, viz.:—

	lbs.		lbs.
Best Welsh coal . . .	9·5	Average small Newcastle . .	8·07
Anthracite	9·01	Average Welsh.	8·04
Best small Newcastle. .	8·52	Average large Newcastle . .	7·66

M. Cavé's Experiments.—Some recent experiments on the

evaporating power of cylindrical boilers ashore, made by M. Cavé, of Paris, give a mean result of 8·2 lbs. water for 1 lb. coal.

Description of the Boiler used in the Parliamentary Experiments.—The boiler employed for the Parliamentary Experiments was made on the Cornish principle, being cylindrical, with flat ends and an internal flue, within which the grate was placed, at one end. The hot air and gases, after leaving the furnace, passed through the central flue to the other end of the boiler, where they divided into two streams, and returned to the front of the boiler, along the outside, by a flue on each side; these two were then united again under the front of the boiler, and returned along a flue under the bottom of the boiler, finally entering the chimney after a course of about thirty-six feet. The grate surface was five square feet, and the total heating surface of the boiler 197·6 square feet. The boiler was worked under a pressure of from 1 to 3 lbs. on the square inch.

Management of the Fire.—In the management of the fire, care was taken to supply the coals in pieces not exceeding 1 lb. weight, and in quantities of not more than one or two shovelfuls at a time, spread evenly over the fire, except in the case of anthracite, and of highly bituminous coal. With anthracite, it was found that the sudden application of heat caused the pieces to split and fall through the bars; hence a gradual heating on the dead plate in front of the furnace, which in the experimental boiler was ten inches wide, was found to be beneficial. With the highly bituminous coals, also, a partial coking on the dead plate prevented their caking together on the fire, which would have impeded the passage of air through the bars.

On Patent Fuels, their Advantages and Defects.—The Report states, that as the varieties of patent fuel are generally

made up in the shape of bricks, they are well adapted for stowage, so that though the specific gravity of patent fuels is lower than that of ordinary coals, yet, from their shape and mechanical structure, there are very few coals that could be stowed in a smaller space per ton. While we look to the different varieties of patent fuel as of the highest importance, and from their facility of stowage as being peculiarly adapted for naval purposes, and perhaps even destined to supersede ordinary coal; at the same time, the greater part do not appear to be manufactured with a proper regard to the conditions required for war steamers. It is usual to mix bituminous or tarry matter with bituminous coal, and from this compound to make the fuel. An assimilation to the best steam coals would indicate, however, the very reverse process, and point to the mixture of a more anthracite coal with the bituminous cement. As the greater part is at present made, it is almost impossible to prevent the emission of dense opaque smoke, a circumstance extremely inconvenient to ships of war, as betraying their position at a distance at times when it is desirable to conceal it. Besides this and other inconveniences, the very bituminous varieties are not well suited to hot climates, and are as liable to spontaneous combustion as certain kinds of coal. To avoid these inconveniences some kinds of patent fuel have been subjected to a sort of coking, and thus in a great measure obtain the desired conditions. There is little doubt, however, that notwithstanding the large number of patents in operation for the manufacture of fuel, its value for the purposes of war steamers might be much enhanced by its preparation being specially directed to this object. It will be seen by reference to the Table, that the three patent fuels examined rank among the highest results obtained.

Rapid Corrosion of Iron Coal Bunkers.—The retention of coal in iron bunkers, if these are likely to be influenced by moisture, and especially when by any accident wetted with sea-

water, will cause a speedy corrosion of the iron, with a rapidity proportionate to its more or less efficient protection from corroding influences. This corrosion seems due to the action of carbon, or coal, forming with the iron a voltaic couple, and thus promoting oxidation. The action is similar to that of the tubercular concretions which appear on the inside of iron water pipes when a piece of carbon, not chemically combined with the metal, and in contact with saline waters, produces a speedy corrosion. Where the "make" of iron shows it liable to be thus corroded, a mechanical protection is generally found sufficient. This is sometimes given by Roman cement, by a lining of wood, or by a drying oil driven into the pores of the iron under great pressure.

Gases evolved from Coal during Exposure to the Atmosphere.—Recent researches on the gases evolved from coal, prove that carbonic acid and nitrogen are constantly mixed with the inflammable portion, showing that the coal must still be uniting with the oxygen of the atmosphere, and entering into further decay. Instances have frequently occurred of men who had descended into the coal boxes having been rendered insensible by the carbonic acid collected there.

Natural Decay in Coal.—Decay is merely a combustion proceeding without flame, and is always attended with the production of heat. The gas evolved during the progress of decay in free air consists principally of carbonic acid, a gas very injurious to animal life. It is well known that this change in coal proceeds more rapidly at an elevated temperature, and therefore is liable to take place in hot climates. Dryness is unfavourable to the change, while moisture causes it to proceed with rapidity. When sulphur or iron pyrites (a compound of sulphur and iron) is present in considerable quantity in a coal still changing under the action of the atmosphere, a second powerful heating cause is introduced, and both acting together may produce what is called *spontaneous*

combustion. The latter cause is in itself sufficient, if there be an unusual proportion of sulphur or iron pyrites present.

Spontaneous Combustion.—The best method of prevention in all such cases is to ensure perfect dryness in the coals when they are stowed away, and to select a variety of fuel not liable to the progressive decomposition to which allusion has been made.

Advice in the Selection of Fuel.—It may be desirable to sum up in a few words some of the principal points alluded to in this Report. It has been shown that the true practical value of coals for steam purposes depends upon a combination of qualities which could only be elicited by carefully and properly continued experiments. Their qualities, so far as regards steam ships of war, may be stated as follows:—

1. The fuel should burn so that steam may be raised in a short period, if this be desired; in other words, it should be able to produce a quick action.

2. It should possess high evaporative power, that is, be capable of converting much water into steam with a small consumption of coal.

3. It should not be bituminous, lest so much smoke be generated as to betray the position of ships of war, when it is desirable that this should be concealed.

4. It should possess considerable cohesion of its particles, so that it may not be broken into too small fragments by the constant attrition which it may experience in the vessel.

5. It should combine a considerable density with such mechanical structure, that it may easily be stowed away in small space; a condition which, in coals of equal evaporative values, often involves a difference of more than 20 per cent.

6. It should be free from any considerable quantity of sulphur, and should not progressively decay, both of which circumstances render it liable to spontaneous combustion.

All the Good Qualities are never united in one Coal.—It

never happens that all these conditions are united in one coal. To take an instance, anthracite has very high evaporative power, but not being easily ignited, is not suited for quick action; it has great cohesion in its particles, and is not easily broken up by attrition, but it is not a caking coal, and therefore would not cohere in the furnace when the ship rolled in a gale of wind; it emits no smoke, but from the intensity of its combustion it causes the iron of the bars and boilers to oxidate, or waste rapidly away. Thus, then, with some pre-eminent advantages it has disadvantages which, under ordinary circumstances, preclude its use.

By a due attention to these practical hints, the commander of a steam vessel will be enabled to strike a balance between the good and bad qualities of the fuel offered him for sale, and to select that which appears likely to fulfil most of the conditions which his peculiar service may demand.

Tables of the "Economic values of different coals and patent fuels;" of the "Mean composition of average samples of the coals;" and of the "Substances produced by the destructive distillation of certain coals," will be found at the end of the book.

Wood used as Fuel in Steam Vessels.—When wood is used for fuel in steam vessels, it requires from 2½ to 3 lbs. (according to the degree of dryness) to equal one pound of coal. Wood tolerably well dried contains one-fifth of its own weight of water, in evaporating which about one quarter of the whole heat generated is absorbed; peat, on the contrary, contains only from 1 to 3 per cent. of "hygroscopic" water.

Turf used as Fuel in Steam Vessels.—Turf has been occasionally used for fuel in steam boats, though not hitherto with much success. Its calorific value depends wholly upon the degree of dryness to which it has been brought, and when kiln-dried it is found to have a strong tendency to re-absorb moisture; so it should be used as soon after this process as

possible. When burnt in a tubular marine boiler with $6\frac{1}{2}$ square feet of grate bar and 280 square feet of total heating surface, it required 51 lbs. of good peat to evaporate one cubic foot of water, being about one-sixth of the duty of coal.

A table showing the economic value of different coals will be found in the Appendix.

CHAPTER XI.

CONSIDERATIONS AFFECTING THE CONSUMPTION OF FUEL AND GENERAL EFFICIENCY OF STEAM VESSELS.

Rate of Consumption of the Fuel in a Steam Vessel.—The rate of consumption of the fuel in a sea-going steamer is a consideration of the first importance, not merely as it regards the question of expense, but also as it affects the capability of the vessel for increasing the length of her voyage under steam, as well as her safety in case of unusual detention from adverse weather. It is proved alike by theory and experience, that under ordinary circumstances of weather, a vessel will steam further with a given quantity of coals, by using only a fraction of her steam power, than she would if going at full speed. Theoretically speaking, the slower the vessel's speed, the greater the economy of fuel, provided always that no steam escape from the safety valve, or is otherwise wasted; but if her progress be opposed by contrary winds and currents, the engines should of course exert sufficient power, not merely to preserve her position, but to give forward motion if possible.

Steaming against the Stream.—In this case it is found that the power is applied most economically when the vessel steams half as fast again as the velocity of the opposing stream or current. Thus, if the vessel be steaming up a river, or in a tideway where the current runs at four knots an hour, her speed should then not be less than six knots.

Natural Law regulating the Speed of a Steamer.—These results chiefly depend upon the natural law that *the power expended in propelling a steam ship through the water varies as*

the cube of the velocity. This law is modified by the retarding effect of the increased resisting surface consequent upon the weight of the engines and fuel, so that the horse-power increases in a somewhat higher ratio than that named.

Limit imposed to the Possible Speed.—This consideration imposes a limit to the possible speed of a steamer, depending upon the weight of the machinery and fuel which it can carry, relatively to its dimensions and tonnage. It is apparent also that this limit is extended according as the proportions of the engines and vessel are increased, for the larger the engines the less is their weight per horse-power, and the greater is the effect of the steam in the cylinders; while the larger the vessel, the less is the resisting surface increased by the displacement of each additional ton of machinery and fuel.

That the velocity of the ship varies as the cube root of the power, is amply confirmed by experience, and (amongst others) by the following trials made with H. M. Screw Steamer *Desperate* :—

Trial.		Indicated Horse-power.	Speed in Knots.
Mar. 1	With 4 boilers and 4 cylinders . . .	805·89	9·15
2	With 3 boilers and 4 cylinders, working expansively	572·32	8·25
3	With 2 boilers and 4 cylinders, working expansively	363·87	7·35
4	With 1 boiler and 2 cylinders, working expansively	169·32	5·98

During these trials the consumption of coal (hand-picked Welsh) was never lower than 4·4 lbs. per indicated horse-power per hour, nor greater than 5·9 lbs., in any of the experiments, the best result being obtained when a single boiler only was used,—showing that during those trials no economy

resulted from "slow combustion." The most economical rate of combustion was about 18 lbs. of coal per square foot of grate-bar surface per hour.

To find the Speed corresponding to a Diminished Consumption of Fuel.—Hence, if a vessel of 500 horses' power, we shall suppose, have a speed of 12 knots, with a consumption of 40 tons of coal per diem, if we wish to find the speed corresponding to a diminished consumption of 30 tons per diem, the following simple calculation is required, viz. :—

$$40 : 30 :: 12^3 : V^3 \text{ (cube of the required velocity).}$$

$$\text{Or, reduced, } 4 : 3 :: 1728 : V^3,$$

$$\text{As an equation, } 3 \times 1728 = 5184 = 4\,V^3,$$

$$\text{Or, } \frac{5184}{4} =$$

$$\sqrt[3]{1296} = 10{\cdot}902 \text{ knots} = V, \text{ required velocity.}$$

Thus, by diminishing the horses' power, or the consumption of fuel, of this vessel by one-fourth, we lose only a little more than one knot per hour in the resulting speed.

The same calculation may be applied for comparing the effects of engines of different power in the same vessel, or of the same engines when worked at reduced power.

The results thus obtained are of course independent of the additional advantage gained by expanding the steam in the cylinders, which, in the case of large engines working at low powers, is very considerable.

To find the Consumption of Fuel corresponding to an Increased Speed.—Again, if we find that the speed of our vessel has advanced from eight knots (we will suppose) to nine knots, in consequence perhaps of her having received new boilers, and using more steam in the cylinders, and we wish to find the corresponding increase in the consumption of fuel, the following calculation will be necessary, viz. :—

$8^3 : 9^3 ::$ former consumption : present consumption,

$512 : 729 ::$ Ditto : Ditto

Or, in the ratio of 1 to 1·424.

Relation between the Consumption of Fuel, and the Length and Velocity of the Voyage.—Again, the consumption of fuel during two or more voyages of known lengths will vary in the proportion of the square of the velocity multiplied by the distance traversed.

Thus, if we find that during a voyage of 1200 miles, performed at the average speed of ten knots, the total consumption of fuel is 150 tons, and if we now wish to ascertain the consumption for a longer voyage (of 1800 miles, we will suppose), at a reduced speed of eight knots, the calculation will be as follows:—

150 tons : C required consumption :: 10^2 knots × 1200 miles : 8^2 knots × 1800 miles.

Then, $C \times 100 \times 1200 = 150 \times 64 \times 1800$,*

Or, $C \times 120{,}000 = 17{,}280{,}000$

Reduced to $C = \frac{1728}{12} = 144$ tons consumption.

If, on the other hand, we require to know at what rate the vessel must steam in order that her consumption during the longer voyage of 1800 miles may not exceed her previous consumption of 150 tons during a voyage of 1200 miles at ten knots an hour, the calculation will be as follows:—

If we substitute 150 tons (our supposed consumption) for C in the equation above, marked thus*, and V^2 (the square of the required velocity) for 64, we shall then have,

$$150 \times 100 \times 1200 = 150 \times V^2 \times 1800,$$

Or, $120{,}000 = 1800\ V^2$,

Reduced, $\frac{1200}{18} = V^2$,

And $V = \sqrt{66{\cdot}66} = 8{\cdot}15$ knots.

Economy attending a diminished Speed in the Vessel.—These examples all show the great economy which attends a diminution of speed in the vessel; and although in the case of merchant steamers, the loss of time is generally too serious a

disadvantage to admit of any permanent reduction of speed, much benefit has resulted to ships in the Royal Navy from the judicious husbanding of the fuel in this manner, whether it be to meet the requirements of an unusually long run, or merely to save coal when the vessel is employed on a service not demanding extraordinary despatch.

Use of Sails of a Steamer.—The steamer's sails, also, form a most important addition to her capabilities, as for each knot that the vessel is propelled by their aid, as much fuel is saved as may afterwards propel her the same number of knots in a calm. The sails should therefore be set upon every occasion of a fair wind, and according as it is more or less favourable, so should the steam be more or less cut off and expanded in the cylinders. By this means we avoid the unnecessary consumption of dense steam, which would otherwise be used at a disadvantage; for it is evident, that however little the engines may assist in propelling the ship, they must nevertheless work very fast in order to overtake the vessel's speed generated by the sails alone, and two cylinders full of steam must always be used for each revolution.

Many of our screw steamers sail extremely well under canvas. Thus, the *Indiana* has been known to make 970 knots in three days, under sail alone. The maximum speed of this vessel with steam alone, is 10 knots, and her average speed in a long run is from 8½ to 9 knots an hour, steaming and sailing. It is believed that a steamer's sails, those of a screw steamer more especially, might be much more frequently used than they are, with manifest advantage in saving steam, but for the strong temptation to the commander of sparing his officers and crew at the expense of the engines.

Disconnecting the Engines.—When a moderate speed can be attained by the sails alone, it is more economical (though otherwise not always to be recommended) to stop the engines entirely, and disconnect the wheels or screw when practicable,

suffering them to revolve freely in their journals by the reaction of the water. In the case of the screw, it may either be raised entirely out of the water (if provision be made for this) or the blades feathered, as will be hereafter explained. When, on the other hand, the wind and sea are adverse, the full power of the engines must be applied, every knot gained being now of double value.

In steaming head to wind with a paddle-wheel steamer, it is found to be the best practice to keep the vessel in a direct course as long as possible, but so soon as she begins to fall off, first to one side and then to the other, for want of good steerage-way, the fore and aft sails should be set, and the vessel tacked, the engines being kept working all the time. In the screw steamer, on the other hand, there is no economy in keeping a direct course against a head wind and sea after her speed is reduced to two or three knots per hour, since the engines keep up nearly their usual number of revolutions, and the steam is almost all wasted in slip. In such a case, therefore, the ship's course should be altered, and the sails set to assist the screw, so soon as the speed falls to this degree. In paddle-wheel engines the waste of steam in going head to wind is not so great, since the revolutions decrease with the speed of the vessel.

To compare the General Efficiency of different Vessels.—It will be apparent from what has been already said, that it is very difficult, if not wholly impracticable, to institute a just comparison between the degrees of efficiency of different steam vessels. In the first place, the performance of the machinery has to be separated from the question of the form of the vessel, if we would enter minutely into the subject; and the performance of the machinery itself should again be subdivided into the relative efficiency of the *engines* and *boilers*.

But as it cannot be expected that mercantile men should enter into these details, a simple method of drawing a general

and approximate comparison between different vessels, taken as a whole, may be found useful.

For Commercial Purposes.—It is at once apparent that the mere statement of the number of miles run for one ton of coals, can be a just criterion only between vessels of the same or nearly equal size, making the same voyage, at nearly equal speeds, and that it is by no means applicable as a general standard, since a ton of coals will, as a matter of course, carry a small vessel further than it will a larger one. As we have seen, too, that an increase of speed is obtained only at the expenditure of a very great increase of power, a proper allowance must also be made for this. Hence, to draw even the most superficial comparison between the "efficiency" of two steam vessels, their speeds must first be reduced to a common standard, and the relation must then be found between the consumption of the fuel at this speed and the size or tonnage of the vessel, the *maximum speed* of each being considered as a separate question. The signification of the term *efficiency*, varies so materially in different classes of vessels, that steamers of the same class only can be justly compared together; the speed required by any particular service, or in other words, the estimation of *time* in each service, being a totally distinct consideration, as regards consumption of fuel and general efficiency. Thus, one vessel may make a voyage at a slow rate, and with a small consumption of fuel, while another vessel of the same power and tonnage, although it may be of very decidedly superior "efficiency," may consume a much greater quantity of fuel, by performing the same voyage in a much shorter time. In the Government service, the time occupied by a voyage is usually not so much considered as a low consumption of fuel, and the vessel is therefore limited to a slow and economical speed. In the case of merchant steamers, on the other hand, this system would be the reverse of economy.

It is believed, that if the number of register tons carried

by one ton of coals, at the rate of ten knots an hour, be taken as a common standard of comparison for estimating the duty of sea-going steamers, it will be found sufficiently accurate for mercantile purposes, the maximum speed of the vessel being treated as a separate consideration.

Example No. 1.—Suppose, for example, that a vessel of 1300 tons, and 500 horse-power is found by experiment, when at her medium draught of water, to make 10·5 knots an hour, with a consumption of three tons of coal per hour.

To reduce her performance to the proposed standard, therefore, the following calculation must be made:—

$$10{\cdot}5 \text{ knots} : 10 \text{ knots} :: \sqrt[3]{3 \text{ tons, present consumption}} : \sqrt[3]{\text{required consumption.}}$$

Cubing these quantities, and working out the proportion, we have

$$1157{\cdot}625 : 1000 :: 3 : 2{\cdot}59 \text{ tons, required consumption.}$$

We have thus found that 1300 tons (tonnage) are carried 10 knots in an hour, by a consumption of 2·59 tons of coals: Therefore,

$\frac{1300}{2{\cdot}59} = 501{\cdot}9$ tons (tonnage) carried by this steamer a distance of 10 knots in an hour, by one ton of coals.

Example No. 2.—Again, a vessel of 1072 tons, and 400 horse-power, is propelled at the rate of 10·4 knots, with a consumption of 48½ cwt. of coals per hour.

$$\text{Then, as before, } 10{\cdot}4 : 10 :: \sqrt[3]{48{\cdot}5} : \sqrt[3]{\text{required consumption.}}$$

$$\text{Or, } 1124{\cdot}8 : 1000 :: 48{\cdot}5 : 43{\cdot}1.$$

And now, 43·1 : 1072 :: 20 : 497·4 tons (tonnage) carried by this steamer a distance of 10 knots in an hour, by one ton of coals.

The comparison between those two steamers, therefore, shows that their performance is nearly equal, being in the proportion of 501·9 to 497·4.

To compare the Efficiency of Different Vessels for Scientific Purposes.—If it be wished to form a more scientific and accurate comparison, the separate question of the efficiency of the

boiler being ascertained by an experiment as to weight of water evaporated by 1 lb. of coal, and the efficiency of the engine by finding the quantity of steam used in it to produce an indicator horse-power, it will be necessary to substitute the *indicator horse-power* for the *consumption of fuel*, and the actual *displacement* of the vessel for the *nominal tonnage*. With regard to the latter point, it is much to be regretted that a certain petty jealousy still existing amongst ship builders, though now happily exploded amongst engineers, frequently steps in to obstruct the investigation of all questions relating to the form and displacement of a vessel's body, by withholding the design from which it was built. As the lines of the vessel cannot be deduced from the scale of displacement,* however, we think that every owner of a steamer may insist upon this being supplied to the captain of his ship, without taxing too far the communicativeness of the designer, who, it would appear, is apt to forget that only quacks and charlatans work in secret, while with the true scientific practitioner all is open and above-board, and publicity courted with a view to criticism and discussion, and consequently progressive improvement.

The number of tons of displacement, therefore, that 100 gross or indicator horse-power will propel at the rate of ten knots an hour, is proposed as a standard of comparison for enabling us to judge of the relative values of different forms of vessels.

Example No. 1.—A vessel, upon trial, is found to have a speed of 10·5 knots an hour, the engines exerting an indicator power of 1440 horses, and the displacement being at the same time 2380 tons, as taken from the scale of displacement.

Then, as 10·5 knots : 10 knots :: $\sqrt[3]{1440}$ H.-P. : $\sqrt[3]{\text{indicator power required.}}$

Or, 1157·625 : 1000 :: 1440 : 1243·9.

* For an example of a scale of displacement, see Rudimentary Treatise on Shipbuilding, Vol. I. in this series, Plate C.

And 1243·9 : 2380 :: 100 : 191·3 = tons of displacement propelled, in this vessel, by 100 indicator horse-power, at the rate of 10 knots an hour.

Example No. 2.—Another vessel, on trial, is found to have a speed of 10·4 knots; her engines exerting an indicator power of 919·6 horses, and her displacement at the same time being 1323 tons.

Then, as 10·4 knots : 10 knots :: $\sqrt[3]{919{\cdot}6}$ H.-P. : $\sqrt[3]{\text{required H.-P.}}$

Or, 1124·8 : 1000 :: 919·6 : 817·5.

And 817·5 : 1323 :: 100 : 161·8 = tons of displacement propelled, in this vessel, by 100 indicator horse-power, at the rate of 10 knots an hour.

Considerations to be attended to in proportioning the Horse-power to the Tonnage.—In proportioning the horse-power of a vessel, the fact is seldom borne in mind, that the effective power of the engines increases in a higher ratio than simply as the tonnage, the resistance of the water to the hull of the vessel varying as the square of the cube root of the tonnage. Thus, if a vessel of 1000 tons and 500 horses' power have a speed of 12 knots, a vessel of 1600 tons and 800 horse-power ought, *cæteris paribus*, to have a considerably greater speed, since the square of the cube root of 1600 ($\sqrt[3]{1600^2}$, or $11{\cdot}7^2$) is 684 horses' power only. This law is somewhat neutralized in practice by the fact of the *displacement* usually increasing in a higher ratio than the *nominal tonnage*. If it be desired to design a vessel of a proposed size and speed, the safest mode of proceeding is to take the vessel nearest in tonnage and general description to that which it is intended to construct as a groundwork. If greater speed is required, the natural law, as given in page 125, will be the guide as to the amount of additional power that will be necessary; thus, if a vessel of 1000 tons and 400 horses' power now running, is found to have an average speed of ten knots, and it be desired to have a vessel of the same tonnage, with a speed of eleven knots, the proportion becomes

$10^3 : 11^3 :: 400 :$ horse-power required.

By means of this proportion, 532 horses' power is found

to be necessary, supposing the new vessel to be of no better form, and the engines to work to the same amount of excess of indicator over nominal horse-power. Much may undoubtedly be done by an improvement in form, but too much ought not to be expected from it, and though some faults may be very apparent in the original, and be capable of remedy, yet it ought not to be assumed that the new vessel will be entirely free from all retarding causes.

Comparisons between the Performance of Government and Merchant Steamers are generally imperfect.—Unjust comparisons are frequently made between the performance of Government and merchant steamers; for when we consider the peculiar qualifications demanded by a vessel of war, it will be seen that the comparison cannot be made on equal terms. War steamers are built not only to steam but to *sail* well; and moreover they must be able to carry a great weight of armament on the upper deck without prejudice to their stability, and since the only effectual way of doing this is by giving them a greater relative breadth than merchant steamers are limited to, the consequence is, that the hull opposes an increased resistance to the water, and the speed is diminished. Then the weight of hull and equipment of a war steamer is usually much greater than in the merchant service, causing a corresponding increase of displacement; the masts, yards, and rigging, being of greater dimensions, oppose a greater resisting surface to the air; and owing to the weight of the large guns at the extremities of the vessel demanding support from the upward pressure of the water, the lines at the bow and stern cannot be made so fine as might otherwise be desirable. Hence it follows, that the speed of the contract mail steamers, for instance, averages from one to one and a half knots above that of vessels in the navy, with a similar proportion of power to tonnage; but if the proportion of horse-power to *displacement* be taken, the comparison will generally become more favourable to the war steamer.

Economy of Steam Power the best Criterion of Efficiency in the Navy.—In estimating the performance of a Government steam vessel, therefore, we should look rather to the direct distance run by the combined action of steam and sails, at a moderate but uninterrupted speed, and with a low rate of consumption of steam and fuel, than to the attainment of a high velocity, which is seldom wanted in war steamers. The best exposition we can offer of the practical working of this combined system of steaming and sailing in the navy, has been supplied by Capt. Hoseason, in his account of the performance of the steam sloop *Inflexible*.

Performance of the Inflexible *in a Steam Voyage round the World.*—This vessel, designed by Sir W. Symonds, is of 1122 tons burden, and 378 horses' power. The engines are direct-action, by Fawcett, and the boilers are loaded to 8 lbs. on the square inch. The whole distance run (without counting going in and out of harbour) during the time she was in commission, from the 9th of August 1846, to the 28th of September 1849, was as follows:—

Steamed	64,477 nautical miles.
Sailed	4,392 „
	68,869 „
Number of days under steam	345¼
„ under sail alone	27½
	372¾
Average daily steaming	186·62 knots.
Average daily sailing	161·18 „
For the whole period	57·44 „
Time under one boiler	76¾ hours.
„ two boilers	4047 „
„ three „	3324½ „
„ four „	844 „
	8,292 hours.

Her fires have been lighted 483 days. Total consumption of coals while under steam, 8121 tons 12¾ cwt.; coals expended in raising steam and

banking the fires, 576 tons 16¾ cwt.; average distance steamed per ton of coals, 7·938 knots. Consumption of coals per hour, 19,588 cwt.; ditto per day, 23 tons, 10 cwt., 12¼ lbs.; average consumption of coals per nominal horse-power per hour, 5·85 lbs.

It is stated that the above-mentioned distances were obtained by the patent log, towed about 50 fathoms astern, out of the influence of the backwater from the wheels; the error arising from this cause, while throwing the common or hand-log, having been found on board the *Inflexible* to vary from one to four knots. It is recommended, therefore, that the patent log only should be used by a steam vessel, its results being verified by the bearings of the land, when the distances are known.

The expenditure of coals was taken by measuring every tenth bag in the ship, and every tenth bag as used by the fires, a mean being taken every four hours for the hourly expenditure.

Performance of the Inflexible.—The distance accomplished by the *Inflexible* is stated to have been reckoned only from the time the patent log was thrown overboard, and when the final departure from the land was taken.

It is further stated that she was employed for fifteen months on the coast of New Zealand, during which time about 4000 tons of the Newcastle Australian coal were consumed, the best quality of which, delivered at the mines, is about ten per cent. inferior to good English coal, but rendered fully 25 per cent. inferior by being exposed on the open beach at New Zealand. A deduction should therefore be made for this circumstance, in considering the expenditure of fuel.

On the outward voyage of the *Inflexible* to the Cape of Good Hope, in the months of August and September 1846, a run of 5502 nautical miles was accomplished on a single coaling, at a mean average speed of 7·31 knots per hour, and an average daily expenditure of 12 tons, 19 cwt. 3 qrs. 14 lbs. This run was accomplished in 32 days.

On the voyage from the Cape of Good Hope to Port Jack-

son, Sydney, 5356 nautical miles were accomplished at one coaling, with an expenditure of 458 tons 10 cwt., being at the rate of 15 tons, 3 cwt. 2 qrs. per diem, and with a mean average speed of 7·87 knots per hour. Time taken, 30½ days.

In calculating the consumption of coal as above, an allowance of 5 per cent. for "*wastage*" has been added to the actual weight burnt in the fires, such allowance being made in order that the captain may judge of the quantity of coals remaining in the boxes at any time. This percentage was determined by experiment during the *Inflexible's* first two voyages, when the difference of weight was accurately noted between the coals burnt, and those received on board in England. It is thence argued that 5 per cent. should be subtracted from the gross quantity, if the true duty in miles per ton of coals is sought. We confess we are at a loss to account for so large a wastage.

It is further stated that on one occasion, when the full power of the engines was exerted, the *Inflexible* towed the barque *Claudine*, and succeeded in transporting 1500 soldiers, tents, equipage and baggage, 1400 nautical miles in 12 days, four of which were occupied in the landing of one regiment and the embarkation of another.

After service on the coasts of India and China, the *Inflexible* returned to England by Cape Horn, thus making the circuit of the globe, and fulfilling her comprehensive mission in a manner most creditable to her able commander, Captain Hoseason.

Economy of a Moderate Proportion of Horse-power in combination with the Sails.—These results show, in a most favourable light, the economy of a moderate proportion of horse-power in combination with the judicious use of the sails: and it is a question of much interest to the navy whether a better average result might not be expected and obtained from such a system, than from the expensive fashion of loading the vessel with very large engines whose full power is but seldom wanted, and which monopolize so much weight and space that

nt coals cannot be carried for the proper development steam power. It is true, that by the use of a high pro-ion of power to tonnage, the vessel has the advantage of ing always a high speed at her command, *so long as the coals last;* while, by expanding the steam in her large cylinders, she may burn the fuel, on ordinary occasions, most economically, still we must remember the increased first cost of the machinery, and the increase of displacement consequent upon the great extra weight to be constantly carried (whether it be used or not), by which the speed of the vessel is permanently diminished.

A high Proportion of Horse-power requisite in the Merchant Service.—Although we thus advocate the employment of a moderate proportion of power to tonnage for the Royal Navy, this question has a different aspect when considered with reference to the merchant service. For though, as is well understood, any increase of speed requires an increased power in the duplicate ratio of the increased speed, and therefore a great economy would seem to result from the low proportion of power to tonnage; still, if *time* be calculated as an element (and, in reality, a very important one) in the economy of mercantile conveyance, it will be generally found that a high speed, at almost any expense of fuel, will compensate for the additional expense. As regularity of arrival, also, is of the utmost importance in passenger and mail traffic, this can be ensured only by the employment of a high ratio of power; for it is apparent that, should the contrary forces of adverse winds and waves, of tides and currents, equal or exceed the power of the engines, the vessel may burn an indefinite quantity of fuel without making any progress.

Influence of Form on the Speed of a Vessel.—The great influence exerted on the speed of a vessel by alterations in the form or lines of the bottom has been abundantly proved by experiment.

In the case of the *Rifleman*, government screw steamer of

486 tons and 200 nominal horse-power, a speed of 8·09 knots was obtained with 348 indicated horse-power. Her stern-lines were then improved in form, when her speed was thereby augmented to 9·5 knots with 367 indicated horse-power; or 8·01 knots with 188 indicated horse-power, instead of 348, as before.

The *Teazer* originally had a speed of only 6·31 knots, with 176 indicated horse-power; subsequently the stern-lines were made finer, and the engine-power reduced at the same time, when she made 7·68 knots with an indicated horse-power of only 128.

It was shown in the experiments with the *Dwarf*, also, that her speed could be reduced to one-half by filling out her stern-lines, the indicated horse-power being kept the same in each case.

In the *Magnet* the original bow had an angle of 42°, but when this was altered to 23°, the speed was increased from 10·02 knots to 11·75 knots per hour.

H. M. Steamer *Flying Fish* had a speed of 11·60 knots; her bow was then lengthened by 18 feet, when her speed advanced to 12·57 knots. The following are some of the results of the experiments with the *Flying Fish*.

	Revolutions per min.	Indicated Horse-power.	Speed in Knots.
July 3, 1856: *before being altered.*—			
With full power	74½	1106·06	11·603
¾ power	68¼	877·0	11·201
½ power	59	576·0	9·923
Sept. 16, 1856: *with false bow added.*—			
With full power	77	1309·0	12·572
¾ power	68	918·72	11·150
½ power	60	660·18	10·120

These experiments prove (as might have been anticipated) that it is only at the higher velocities that extreme fineness of

lines are of importance, for at half and three-quarter power there is no improvement consequent upon the alteration, and it is only when the full power is exerted that we find the speed advanced by nearly a knot per hour. It is also remarkable that, before the alteration, doubling the power gave an increase of speed of only 1·68 knots; while after the alteration the speed was increased by 2·452 knots by doubling the power. The speed of a steamer is in general very little affected by increasing her length amidships, which fact has been recently illustrated in a remarkable manner in the case of the *Candia*. This vessel, before being lengthened, was 281 feet long, 39 feet broad, and had a draught of 18 feet 6 inches on an even keel; her speed at her trial-trip being 12·55 knots per hour. The *Candia* has since received an additional length of 35 feet, inserted before the engine room, which has increased her measurement by about 300 tons, and her capacity of carrying coals or cargo, on the same draught as before, by 400 tons. A trial was made at Stoke's Bay on the 12th of August, 1857, with this additional weight on board, when her speed was found to be 12·45 knots an hour, being a difference of only one-tenth of a knot from what it was formerly. This highly favourable result is doubtless owing, in a great measure, to the improved trim of the vessel, since formerly she swam rather by the head, whereas since the alteration she trims about 18 inches by the stern. It shows however very plainly that the retarding action of friction between the water and the straight part of the sides and bottom of a vessel, is comparatively unimportant, the main point being the opening and closing of the water at the bow and stern. We have known the speed of a steamer to be improved by as much as a knot per hour by an alteration in her trim. During her last trial, the *Candia* had 800 tons of coal on board (intended to carry her to Calcutta without coaling at the Cape) as well as water and stores.

CHAPTER XII.

THE PADDLE WHEEL.

Varieties of the Paddle Wheel.—With regard to PADDLE WHEELS, it is believed that the common wheel, if properly proportioned and allowed the proper degree of immersion, is preferable, under ordinary circumstances, to any of the "improved" varieties which have from time to time appeared. Of these, the only one which can be recommended, and that only under peculiar circumstances, is the feathering wheel; but it is objectionable from its weight (which is about twice that of the common wheel), from its complexity and consequent liability to derangement, and from its considerable additional expense. There is no doubt but that the feathering wheels will give a better speed to the vessel, so long as they remain in good working order; but they are unsuitable for long voyages and foreign stations, on account of the great wear and tear which is constantly going on, and the frequent repairs demanded. From their weight, also (those of the *Atrato* weigh 100 tons each), they must strain the vessel very much. The *Ripon* was formerly fitted with feathering wheels, but in consequence of the time and expense they incurred for repairs, they were given up, and common wheels fitted, the result being that the vessel lost one knot per hour in speed during rough weather. Feathering wheels require the most superior workmanship, otherwise they are a source of constant annoyance. The common radial wheel with the board divided into two breadths, and one placed on either side of the paddle-arm, is probably the best form of wheel that can be adopted for large steamers.

Variable Immersion the Grand Objection to the Paddle

Wheel.—We have already hinted that the grand objection to the paddle wheel is the unequal "dip" or immersion of the boards, consequent on the varying draught of water, as the coals and stores continue to be consumed on the voyage. A vessel, for instance, with a displacement of 12 tons per inch at the load line, burning perhaps 460 tons of coals during a long run, will swim 3 feet 6 inches lighter, from the consumption of the fuel alone, at the end than at the beginning, so that it is only in the middle of her voyage that the wheels can have the dip best calculated for them.

In large vessels of this class, the feathering floats give a decided advantage in speed, from not being so much affected by a too deep immersion.

The most advantageous Dip.—The most advantageous dip varies with the diameter of the wheel, the speed of the vessel, and the service in which she is employed, as for sea or river navigation. Sea-going steamers of the first class are usually allowed 18 to 21 inches of water over the vertical float at the mean draught; and smaller vessels may have 12 to 15 inches. It is usual in the case of fast river boats to allow only an inch or two over the boards, when the wheels are large. When the wheels are too deeply immersed, they may sometimes be "reefed" by disconnecting the boards, and securing them nearer the centre.

The "Slip" of the Paddle Wheel.—The "slip" of the paddle wheel, by which is meant the excess of its velocity above that of the vessel, is usually reckoned at one-fifth (or 20 per cent.) of the vessel's speed, the wheel being supposed to be well-proportioned, and the water lines of the vessel tolerably good for speed. In feathering wheels the slip is less.

Explanation of Table of Velocities of Paddle Wheels.—As it is of considerable importance to observe and compare the slip of the wheel under different circumstances, or in different ves-

sels, we have prepared a table of velocities of paddle wheels of varying diameters and speeds, in feet per minute, and miles per hour. The "effective diameter" of the wheel may be reckoned by subtracting one-third of the breadth of the boards from each end of the extreme diameter. This subtraction should therefore be made before referring to the Table given in the Appendix. The rule for finding the velocity of a paddle wheel, when its effective diameter and number of revolutions are given, is the following :—

Multiply the diameter by 3·1416 ; multiply the product by the number of revolutions per minute ; multiply the last product by 60 ; and divide by 5280 for the velocity in statute miles, or by 6082·66 for knots per hour.

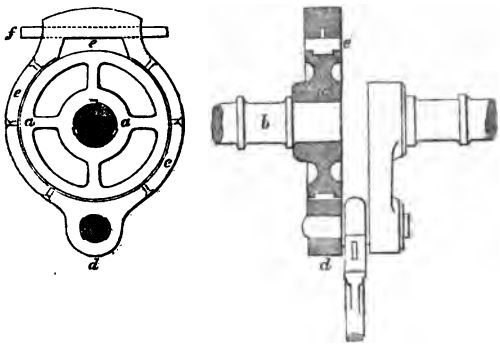
The Table referred to will be found at the end of the book.

Area of the Paddle Boards.—In proportioning the area of the paddle boards, we must take into consideration the estimated dip of the wheels. By taking an average of the practice with regard to large sea-going steamers, we find that the whole paddle-board surface for the two wheels is between $2\frac{1}{2}$ and 3 square feet per horse-power ; but for steamers with a lighter dip, from 4 to 5 square feet are allowed. The surface of each board, for large vessels, rarely exceeds one twenty-fifth of the total horse-power, in square feet ; but increases as the dip and diameter of the wheel diminishes, to about one-fifteenth : while for river steamers one-tenth of the total horse-power is a usual proportion. A long narrow board is more effective than a short and deep one, but is inconvenient, especially in sea-going vessels, from the increased breadth of the paddle box. Thus, in large steamers, the proportion of depth to length varies from one-fourth to one-fifth, but in river steamers the board is generally about seven times as long as it is broad.

Disconnecting the Paddle Wheels.—As it is sometimes desirable to disconnect the paddle wheels from the engines, and

permit them to revolve in their bearings while the ship is under canvas, several kinds of disconnecting apparatus have been employed for this purpose.

Description of a Friction-break Disconnecting Apparatus.—This apparatus is represented in the subjoined woodcut, and it may be thus described. A cast-iron disc, *a*, is keyed on the end of the paddle shaft, *b*, and a strong wrought-iron hoop, *c c*, lined with brass to diminish the friction, surrounds and slides over the periphery of the cast-iron disc. At one side of this hoop, at *d*, a projection is forged, in which the eye is



Friction Disconnecting Apparatus.

bored for the crank pin, and at the other side the hoop is swelled out to receive a brass cushion, *e*, inserted between the hoop and the cast-iron disc. Now, when this cushion is driven hard and tight against the periphery of the disc, by means of a strong key, *f*, the friction between the hoop (in which the crank pin is fixed) and the disc on the paddle shaft becomes so great that the former drags round the latter, and thus communicates motion to the wheels. These are again disconnected by driving back the key, and by this means loosening the friction cushion, when the hoop and the disc revolve each independently of the other.

This apparatus is by no means perfect, and gives much trouble at sea by the slipping of the hoop, notwithstanding that the key may have been driven as tight as possible. The hoop has also itself frequently given way, as the forging is a difficult one to make perfectly sound.

Maudslay's.—Messrs. Maudslay and Field adopt the plan of sliding the paddle shaft, with the outer crank upon it, out of the crank pin, using for this purpose a worm wheel and cogged collar on the shaft, worked from the deck.

Seaward's Plan.—Messrs. Seaward form the pin end of their outer crank with a slot cut out of the thickness of the boss on the inside, the breadth of the slot being equal to the diameter of the pin, which is held fast by square keys in the boss while the engines are working. When it is wished to disconnect the wheels, the engines are stopped, and the keys withdrawn, when the boss of the outer crank clears and passes the pin by means of the slot, as the wheels revolve in their bearings from the resistance of the water.

CHAPTER XIII.

THE SCREW PROPELLER.

The Screw Propeller, its Introduction and Extension.—Dr. Shorter, a practical mechanic of this country, succeeded in propelling a vessel by a screw in 1802; but as no power was at that time known capable of driving his propeller with proper effect, it fell into oblivion. The first introducers of Watt's steam engine to drive a propeller, adopted the paddle wheel; and its success, with such an agent to drive it, seems for a time to have drawn off the current of invention entirely from submerged propellers. Though other patents had been taken out, it was not till Captain Ericsson and Mr. F. P. Smith brought out their experimental vessels in 1837, that any real progress was made. Captain Ericsson's small vessel of 45 feet in length and 8 feet beam, and drawing only 2 feet 3 inches of water, towed the American ship *Toronto*, of 630 tons burden, on the Thames, on 25th of May, 1837, at the rate of 4½ knots per hour against tide, as authenticated by the pilot: and also towed the Admiralty barge, with their Lordships, from Somerset House to Blackwall and back, at the rate of about 10 miles an hour. To Captain Ericsson's anxious application, and after his pointing out the many advantages of a submerged propeller for vessels of war, he received the discouraging reply that their Lordships declined to entertain the project. Later in the same year Mr. Smith made some very successful trips with his small boat and screw propeller between Margate and Ramsgate. The next screw vessel was the *Robert Stockton*, in 1839, built by an American gentleman who had witnessed Captain Ericsson's experiments and taken a favourable and correct view of them. This vessel was eminently successful; but the designer, finding himself still unable to move the Board of Admiralty, left

this country for America, whither this vessel had proceeded, determined to prosecute his invention there. In the meantime some influential mercantile men had connected themselves with Mr. Smith, with the view of purchasing his patent; and the *Archimedes*, a vessel of 232 tons and 80-horse power, was brought out in 1840. The success of this vessel was complete, and the publicity given to her performances by her spirited owners, who took her round Great Britain and showed her powers in every port, rendered the capabilities of the screw no longer a matter of doubt. The Board of Admiralty having received most favourable reports of the performances of this vessel from Captain Chappel, who had accompanied her on this voyage, and from Mr. Lloyd, who had witnessed her performances in making several trips between Dover and Calais in competition with the mail steamers then running, now ordered the *Rattler* to be built on the same lines as the paddle-wheel steamer the *Alecto*, and with engines of the same nominal horse-power. The next screw vessel to be noticed whose performances influenced the progress of the screw as a propeller is the *Dove*, constructed at Liverpool, of iron, under Mr. Smith's direction. The speed realized, however, was not equal to what was expected if she had been fitted with paddle wheels: the owners were in consequence dissatisfied, and ordered her to be altered as quickly as possible to paddle wheels. She was built with very fine lines abaft; and, most unfortunately, from this circumstance, and from some experiments in the *Archimedes* which had proved the possibility of negative slip, Mr. Smith, and those with him, on whose judgment as men of science he relied, took up the idea that full stern lines were the most advantageous for the screw. The *Rattler* was now tried; and, after her trials had fully satisfied the Board of Admiralty, they ordered the construction of several additional screw vessels, and Mr. Smith inculcated his views in favour of full sterns upon their different constructors. This was finally proved to be erroneous, and that a fine run, with a ready access for the water to the screw, and as clear an

escape for it abaft as possible, was absolutely necessary, and the whole of these vessels had to be altered at great cost. In the meantime the screw had risen most rapidly in favour with the public, and fast vessels had been constructed by Mr. Slaughter, of Bristol, with Woodcroft's patent screw, and by other parties, as well as several auxiliary screw vessels.

Since that time the screw has been universally adopted in the ships of the Royal Navy, and its extension in the merchant service for all classes of vessels is also very marked. The fleet of the Peninsular and Oriental Steam Navigation Company affords a remarkable illustration of the favourable light in which the screw is regarded by our large steam ship companies. Formerly the whole of the extensive steam operations of this Company were conducted exclusively by vessels on the paddle-wheel system. Subsequently, the Directors were induced to apply the screw as a motive power in ships of moderate tonnage; the results being satisfactory, as instanced by the performances of the *Madras*, *Bombay*, *Formosa*, *Chusan*, and some other vessels, an inducement to a further extension of the principle was afforded, and the *Bengal* was built, a ship of 2250 tons and 470-horse power. The success of this vessel having proved extraordinary, both in point of speed and economy, the Peninsular and Oriental Company announced its determination gradually to discard the paddle wheel in the whole of its extensive service. Accordingly the following screw vessels were soon after built for the Company, viz.:—the *Himalaya*, of 3500 tons (since purchased by the Government for a troop-ship); the *Simla*, of 2600 tons; the *Candia*, of 2200 tons; the *Colombo*, of 1900 tons; the *Pera*, of 2200 tons; the *Nubia*, of 2200 tons, and others. Several of the paddle steamers of this Company have even been altered into screws.

As regards first cost of hull and machinery, economy of working, and stowage-room for cargo, the large screw steamers of this Company certainly contrast very favourably with the paddle-wheel steamers of the West India and Cunard's Transatlantic lines, although for speed and regularity of transit the

latter have never been surpassed. That large screw steamers have been perfectly successful on the Mediterranean line, admits of no doubt, the only question now at issue being, whether the same vessels, if placed upon the more tempestuous passage across the Atlantic, could compete successfully in speed and regularity with full-powered paddle steamers, such as the *Persia* and *Atrato*. The fact that new steamers for those Transatlantic lines continue to be built with paddle wheels, proves at least that the Directors of their Companies are still doubtful of the expediency of a change.

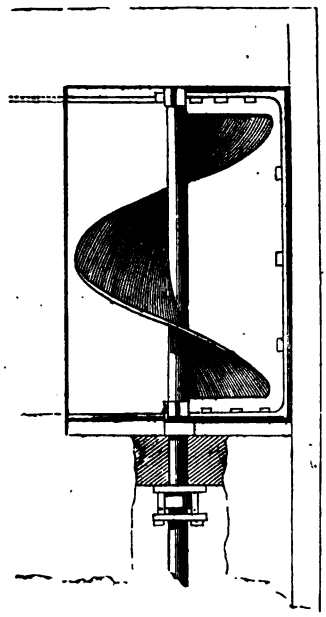
Efficiency of the Screw for War Steamers.—The value of the screw in vessels of war, not only as an auxiliary, but also in full-powered steamers, seems to admit of but little doubt.—A clear broadside for the guns; the comparative safety of the machinery from shot, owing to its low position; the increased stability of the ship from the same cause, enabling her to carry heavier armament on the upper decks; and the freedom of these decks from the machinery; and finally, the power of arranging the masts, sails, and rigging, so as to make her an efficient sailing vessel, are advantages of such moment, that even if the speed realized were inferior to that obtained from paddle wheels, the adoption of the screw would still appear to be justified.

Efficiency of the Screw as an Auxiliary in Sailing Vessels.—The screw, as an auxiliary propeller, to be used either in a calm, or in conjunction with sails in light or contrary winds, stands unrivalled. Several attempts have been made to adapt the paddle wheel and other propellers to this purpose; but they have signally failed to meet the varying circumstances of the ship deeply laden, sailing light, or heeling over under a press of canvas. The efficiency of the screw, however, remains comparatively unimpaired under any of these circumstances.

It must be admitted, however, that the screw has hitherto failed to realize any very decided advantage as an auxiliary to freight-ships making long voyages (as to Australia and India),

h it has been very successful in merchant ships making passages to the Continental or Mediterranean ports.

he Common Screw.—An idea of a screw may be given by posing a line or thread ound round a cylinder, and advancing along it in the direction of its length by a gradual and equal rate of progression. This thread may be of any shape, either triangular, as in many cases, or it may be in the form of a thin plate of metal kept upon its edge, and wound round a cylinder of so small a diameter that it would no longer be called a cylinder, but would become a mere rod or spindle in the centre. This will probably be best understood by reference to the annexed diagram, which represents one thread of this kind wound round a spindle,



and this is called a single-threaded screw. It will be at once evident that two, three, or more threads, if kept uniformly parallel to each other, may in the same manner be wound round the cylinder, and there is then produced a two-threaded or three-threaded screw accordingly. The properties of a screw of this kind were first investigated and made known by Archimedes.

The Pitch of a Screw.—Supposing that a line is drawn along the surface of a cylinder in the direction of its length, and that a line or thread as before, is wound round it, the dis-

tances between the points where the thread crosses the longitudinal line, and which are always the same, is called the pitch of the screw.

The Slip of a Screw.—If a screw be made to revolve in a solid, as a carpenter's screw in wood, it is evident that it will progress in the direction of its axis the distance of its pitch for each revolution, the latter portions following exactly in the course cut by the preceding or first entered portions of the thread. If, however, it be made to revolve in water, which is a yielding medium, the water will to some extent give way, and the screw will not progress the full amount of its pitch, this deficiency in its progress being denominated the slip of the screw.

"*Negative Slip,*" as it has been termed, takes place when the vessel actually goes faster than the rate at which the screw which propels it would advance if revolving in a solid. The explanation offered is, that the vessels in which this occurs have their after lines so badly formed for closing the water, that instead of the hull passing through the fluid with so little disturbance as scarcely to affect its condition of relative rest, a large body of "dead water" is created, which follows the vessel, being *towed* (as it were) in her wake. An opposing current, and therefore an increased resistance, is thus offered to the action of the screw. This seems to have the effect of annihilating the slip, the vessel appearing to outstrip the propeller by virtue of its advancing through still water (relatively to its own motion), while the screw revolves against an opposing stream. It cannot be supposed that in such a case the power of the engines is economically applied, as a much larger portion of the power is expended in towing the dead water against which the screw re-acts, than is afterwards recovered by the increased effect of the screw. Thus, if the rate of progression of the screw be 10 knots through a solid, and if a current flows against it at the rate of three knots, this will be equal to a real progression of 13 knots for the screw, and we need not be

much surprised if the speed of the vessel, under these circumstances, exceeds the apparent speed of the screw by perhaps one knot per hour. Anomalies of this kind most frequently occur in auxiliary screw steamers, where the vessel, after attaining a high velocity by sails alone, still continues to derive additional assistance from the screw, although its speed may not equal that of the vessel.

Dragging the Screw.—In such vessels, therefore, it does not always follow that the engines are no longer useful after the speed attained by the sails is equal to the progression of the screw, but the engineer should under these circumstances watch the thrust of his propeller shaft very narrowly, as there must be a limit to this in all vessels carrying a large spread of canvas. If he find the thrust to cease, he will then know that the screw is "dragging," and will recommend his commander to discontinue the use of the engines, as being no longer serviceable. Direct evidence of the screw "dragging" has been obtained by the fact of a propeller having been carried away by the strain brought upon it from the velocity of the ship due to the sails, exceeding the velocity of the screw. The rupture in this case clearly showed that the blade, which was of iron plate, riveted upon a wrought-iron arm, was torn off *backwards* by the drag brought upon it.

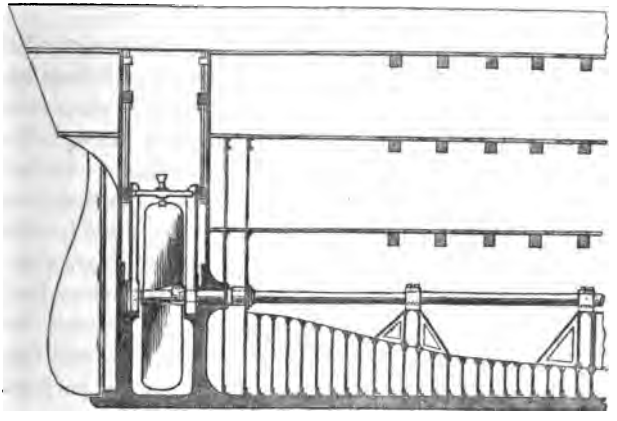
Disconnecting the Screw.—It is usual in the Government service, as well as in auxiliary screw merchant ships, to provide means for disconnecting the screw when the ship is under canvas. This is usually effected by having a hollow trunk constructed over it in the stern of the vessel, into which the screw is lifted, by proper machinery, entirely out of the water, the outer screw shaft fitting into a vertical frame of gun metal, which rises along with it. This will be best understood by reference to the annexed woodcut, which is a section of the stern of a vessel so fitted. The screw is disconnected either by withdrawing the driving shaft out of a socket in the screw

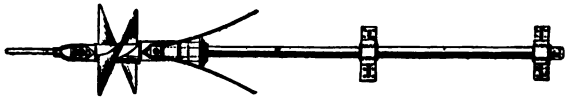
shaft, or, which is the better plan, by forming a coupling on the end of the driving shaft, into which the screw shaft fits and adjusts itself when slipped down between the guides on the trunk. The screw is then retained in its position by a catch pressed down from above upon the gun metal frame supporting the bearings, as well as by its own weight. The screw is raised into or through the trunk by pulleys and ropes worked by the capstan, though an hydraulic apparatus has been sometimes employed; the weight of the screw and its shaft being supported by a pawl and rack on each side of the trunk. In some cases, the screw is only capable of being disconnected from the engines, and left free to revolve by the action of the water upon it, from the motion of the vessel; whilst in other vessels a contrivance is introduced to place the blades in a fore-and-aft direction, so that they may lie within the dead wood of the vessel, and present little or no projecting surface to impede her progress, or affect her steering. In adopting the latter plan it is of course necessary to use a two-bladed screw.

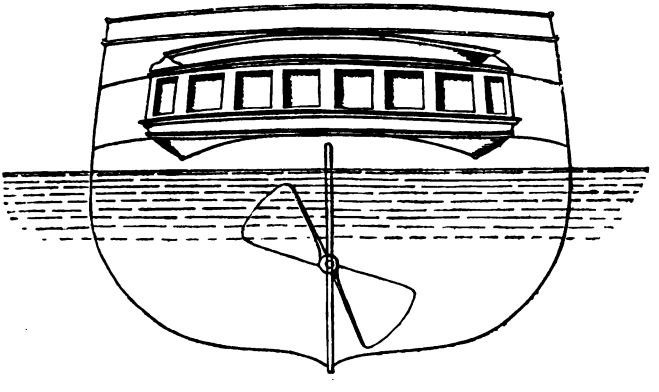
Many screw vessels are fitted with a conical friction-clutch, or coupling, for disconnecting the screw at sea, or connecting it again without stopping the vessel. As this apparatus is liable to cause accidents if not very cautiously used, it is better not to be fitted in vessels which do not frequently require to disconnect the engines.

The Propelling Power of the Screw.—If the spindle of the screw (see fig. in page 151) be supposed to be passed through the side of a box filled with water, and made to revolve there without the power of moving in the direction of its axis, it will send the water away from it with a certain amount of force, and hence, as action and re-action are always equal, the screw is pushed forward with this amount of force; and, if it were attached to a ship, the ship would thus be propelled. The reverse of this action would take place, and the ship would be pulled backwards, if the screw were made to revolve

SECTION OF STERN OF SCREW VESSEL IN THE ROYAL NAVY, SHOWING THE TRUNK OR A PORTION THROUGH WHICH THE SCREW IS RAISED OUT OF THE WATER WHEN DISCONNECTED.



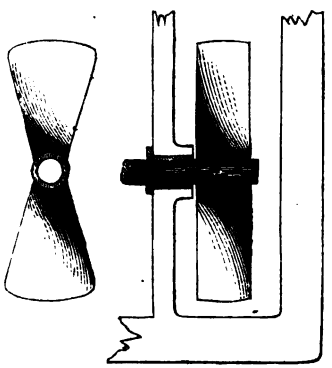




in the opposite direction. From the number of revolutions which a screw propeller of a known pitch makes in a minute, the progress which it would make in an hour is calculated; and, if the speed of the ship be found by observation to be less than this, the difference is the slip.

The mechanical contrivance for receiving the thrust of the screw, and communicating it to the vessel, is sometimes what is termed a "thrust block," of steel, attached to some strong portion of the engine framing, against which the end of the screw shaft presses as it revolves; sometimes a "collared bearing" on the screw shaft. This bearing (generally the one next the engine) is made of an extra length, and is turned with a series of projecting collars or square rings, (six or eight perhaps) which fit into corresponding grooves in the brass linings of the pedestal or pillow block. Collared bearings are now considered preferable to the old-fashioned thrust block. Conical rollers are sometimes used for this purpose.

Explanation of the Term "Screw Blade."—If the screw (see fig. in page 151) be cut into any number of portions by planes passing across it at right angles to the axis, which would be represented in the figure by lines, any one of the portions would have the appearance of the vane of a windmill; and, if the screw were two-threaded, the vanes or blades would be exactly opposite each other, as in the annexed woodcut, which represents a two-bladed screw, as used in propelling. The screw here represented is about one-sixth part only of the whole length or pitch of the full



turn of the screw shown at page 151, this small fraction of the pitch being proved sufficient, in most cases, to absorb the whole power of the engines.

To find the Pitch of a Screw Blade.—This operation proceeds upon the fact, that if a line representing the circumference of the screw's disc at its extreme diameter, and another representing the pitch of the screw, be drawn at right angles to each other, to a scale of parts, the hypotenuse of this right-angled triangle will represent the length of the winding thread. After measuring the diameter in order to find the circumference from it, the length of the blade along its periphery is to be measured, this being a portion of the hypotenuse of the triangle whose sides we wish to determine; then measure the distance that one corner of the blade is before the other in the line of the axis, and this being a portion of the pitch, is a part of another side of the triangle. Now, two sides of a right-angled triangle being known, the third can be found in this case by subtracting the square of the side from the square of the hypotenuse, and finding the square root of the remainder; and the dimension so found will represent a portion of the circumference. And now, as this portion of the circumference is to the whole circumference, so is the portion of the pitch as measured, to the whole pitch.

Varieties of the Screw Propeller.—A great variety of patents for screw propellers were taken out, not only before, but also largely since the success of Captain Ericsson and Mr. Smith; but it is proposed here to refer only to those which have been found successful on trial, and which seem to promise to be of any practical utility. The propellers formed of portions of a true screw, have been already described, and of these Smith and Lowe claimed to be the patentees; the latter party having taken out a patent in September, 1838, for the use of one or more screw blades, similar to what are now generally employed.

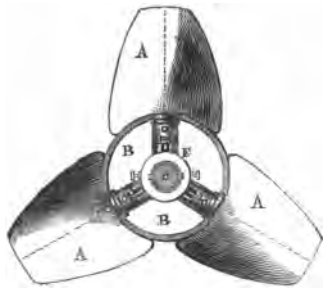
Woodcroft's Screw.—Professor Woodcroft, in his patent of 1832, prior to Captain Ericsson and Mr. Smith, proposed a screw of such construction that the pitch or distance between the revolutions of the thread should continually increase through its whole length, with the view that the after part might act with greater efficiency on the water that had been previously acted upon by the foremost part.

He fell into the error into which Mr. F. P. Smith also subsequently fell, of supposing that one full turn or more of the thread was requisite to make an efficient propeller; and no practical progress was made with his invention, till the first experimental vessels already referred to had been tried and found to be successful. Woodcroft then reduced the length of his screw to that of Lowe's blades, and a trial was made with it in the *Rattler*, when the following results were obtained, in comparison with a propeller of similar proportions, but whose blades were portions of a true screw :—

	True Screw. 18th of March, 1844.	*Woodcroft's Screw.* 13th of April, 1844.
Number of Blades	4	4
Diameter of Propeller	9 ft. 0 in.	9 ft. 0 in.
Length of ditto	1 ft. 7 in.	1 ft. 7 in.
Pitch of ditto	11 ft. 0 in.	11 ft. 0 in. to 11·55 ft.
Strokes of the Engine per minute	26·28	24·152
Mean pressure of Steam, by Indicator	14·38	14·57
Horse-power, by Indicator	459·00	428·76
Speed of Ship	8·180	8·159

To compare these results, we know that if both propellers were equally efficient, the speed should be as the cube roots of the powers exerted ;—now if 459 horse-power gave a speed of 8·180, to find what speed 428·76 ought to give, we must use the following proportion, $\sqrt[3]{459} : \sqrt[3]{428{\cdot}76} :: 8{\cdot}180 : 7{\cdot}9962$. But instead of 7·9962 knots, Woodcroft's screw with this power gave a speed of 8·159, or nearly $\frac{1}{6}$ knot more, thus proving its superiority to this extent in this case.

Griffith's Screw Propeller.—This is probably the best modification of the common screw which has yet been produced. Its chief peculiarity consists in a large hollow sphere, B, being substituted for the central portion of the blades of the ordinary screw, the blades, A A A terminating upon the said sphere instead of upon the usual boss (see p. 151). It has been found by experiment that the central portion of the blades of the common screw absorbs nearly twenty per cent. of the propelling power, without giving out any useful effect, in consequence of that portion of the blades (particularly in coarse-pitched screws) being nearly in a line with the shaft, so that the water is thrown off at right angles, and seriously disturbs the more solid water, upon which the outer and more effective portion of the screw is about to act. The use of the sphere, therefore, is to fill up the space otherwise occupied by the central portion of the screw blades, a smooth globe of this kind revolving in the water with comparatively little friction or resistance.



It is found also that the vibrations which accompany the revolutions of the ordinary screw are considerably lessened by this contrivance, this destructive vibration being chiefly caused by the flatter portions of the screw blades near the root striking the water, with a tendency at the same time to elevate the stern of the vessel, at a considerable sacrifice of power.

The second feature in Griffith's propeller consists in the peculiar form of the blades, which, unlike the common screw, are larger towards the centre and smaller at the extremities. The diameter of the sphere being one-third of the whole diameter of the screw, the breadth of each blade at the root is equal to the full diameter of the sphere, tapering to two-thirds of this size at the periphery, where they are only about

one-third of the breadth of the ordinary screw blade. The object in reducing the blades at the extremities is, to compensate for the varying velocity with which the different parts of the blades travel through the water.

There is still another feature in this propeller, namely, the power of altering the pitch or angle of the blades (whether at sea or in harbour) by a suitable arrangement of apparatus contained within the hollow sphere; or, if it be wished to stop the engines and sail under canvas, the blades may be feathered (as in Maudslay's feathering screw) so as to present their edges to the water, and thus cause the least amount of resistance to the ship. The engineer of the vessel has by this means the power of controlling the speed of the engine within certain limits, by increasing or reducing the pitch of the screw; or if the vessel be sailing and steaming at the same time, he can always command a thrust from the screw by increasing the pitch in proportion as the sailing velocity increases. In practice, this screw is frequently made without the arms being movable, for the sake of greater simplicity and strength. The power of varying the pitch of a screw at sea is not found to be so valuable a property as theory would lead us to expect, and even when possessed, is rarely resorted to;—besides, it is evident that by merely altering the angle at which the blades are set, we do not properly alter the pitch, since they can form portions of a true screw in one position only, namely, when set to the angle due to the pitch for which they were originally moulded.

When the blades of Griffith's screw are made movable, the fracture of one of them (an accident of frequent occurrence with all screws) is repaired by shipping a new blade only, which weighs about one-sixth part of the whole screw. In the merchant service this propeller is usually made with three blades, but when employed in the Royal Navy, it is made with two blades only, for convenience of lifting through the vertical trunk (see page 155). The subjoined Tables show the results of experiments made with this propeller in comparison with the common screw, in H. M. Yacht *Fairy*.

WITH THE COMMON TWO-BLADED SCREW.

Trials.	Revolutions of Engines.	Pressure of Steam.	Vacuum in Inches.	Time.	Knots per Hour.	Average Knots per Hour.	Pitch of Screw.
		lbs.		Min. Sec.			
1. With tide	38½	11	26½	4 49	12·456	12·248	8 ft.
2. Against	38½	11	26½	4 59	12·040		
3. With tide	38	11	26½	4 57	12·121	12·000	8 ft.
4. Against	38	11	26½	5 3	11·880		
5. With tide	38	11	26½	4 49	12·456	12·053	8 ft.
6. Against	38½	11	26½	5 9	11·560		

Total mean speed per hour in knots, 12·100. Draught of water, 7 feet aft, 5 feet forward.

WITH GRIFFITH'S THREE-BLADED PROPELLER.

Trials.	Revolutions of Engines.	Pressure of Steam.	Vacuum in Inches.	Time.	Knots per Hour.	Average Knots per Hour.	Pitch of Screw.
		lbs.		Min. Sec.			
1. With tide	30	11	26	4 57	12·121	11·738	10 ft.
2. Against	30	11	26	5 17	11·356		
3. With tide	33½	11	26	4 34	13·139	12·057	9 ft.
4. Against	33	11	26	5 28	10·974		
5. With tide	37½	11	26	4 51	12·371	12·392	8 ft.
6. Against	37	11	26	4 50	12·413		
7. With tide	41½	11	26	4 23	13·688	12·631	7 ft.
8. Against	42½	11	26	5 11	11·575		

Draught of water, 7 feet aft, 5 feet forward.

The following experiments were made at the measured mile at Stoke's Bay, with the auxiliary screw steamer *Dane*, in order to determine whether Griffith's screw should be substituted for the common screw in that vessel.

The *Dane* is an iron vessel of 532 tons, builder's measurement, and 60 horse-power (nominal).

Diameter of cylinders, each 24½ in.

Length of Stroke, 3 ft.

Length of vessel between perpendiculars, 177 ft.

Extreme breadth, 24 ft. 6 in.

Depth, 16 ft. 7 in.

Draught of water at both trials, 12 ft. aft, and 9 ft. forward.

Pressure of steam in the boilers, 13 lbs.

At the trial of February 20th, 1857, the *Dane* was fitted with a common three-bladed screw of the following dimensions:—Diameter of the screw, 10 it. 6 in. Pitch of screw (uniform), 18 ft. Length on screw shaft, 2 ft., the ends of the blades cut to a semicircular form. With this screw the mean average speed obtained was 8·5 knots per hour for the speed of the ship; the engines making 58 revolutions per minute.

At the trial of February 25th, Griffith's two-bladed screw was fitted, having the following dimensions:—Diameter of screw, 10 ft. 6 in. Pitch (uniform), 18 ft. 6 in. Length on screw shaft, 2 ft. The total propelling surface of the blades being 20 square feet. The blades of this screw were cast solid on the sphere, no provision being made for shifting or feathering. With this screw the mean average speed obtained was 8·67 knots per hour, the engines making 63 revolutions per minute.

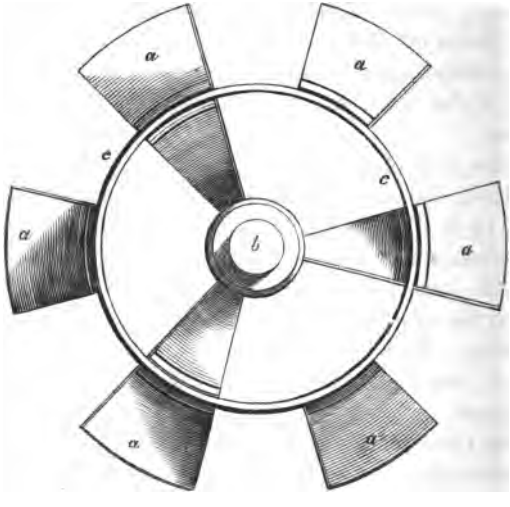
When the speed of the engines was reduced to 58 (the same as on first trial), the vessel's speed fell off to 8 knots.

The vibration caused by Griffith's screw was decidedly less than from the first screw.

Notwithstanding that this result does not show any decided superiority for Griffith's screw, the owners of the *Dane* deter-

mined upon giving it a trial; and they are now so well satisfied with its performance at sea, that they are about to adopt it in all the vessels of the Union Screw Company. When the ship is sailing under canvas, and Griffith's screw is placed in a position with its two blades vertical, it is found to obstruct the vessel's way less than any other screw with fixed blades, so that neither a disconnecting apparatus, nor trunk for lifting it out of the water, is required. In the case of vessels fitted without these appliances, therefore, this must prove a valuable property for a screw to possess.

Ericsson's Propeller.—Captain Ericsson's propeller consists of a number of blades fixed at a distance from the axis, upon the periphery of a short cylinder, or ring of metal; the ring be-



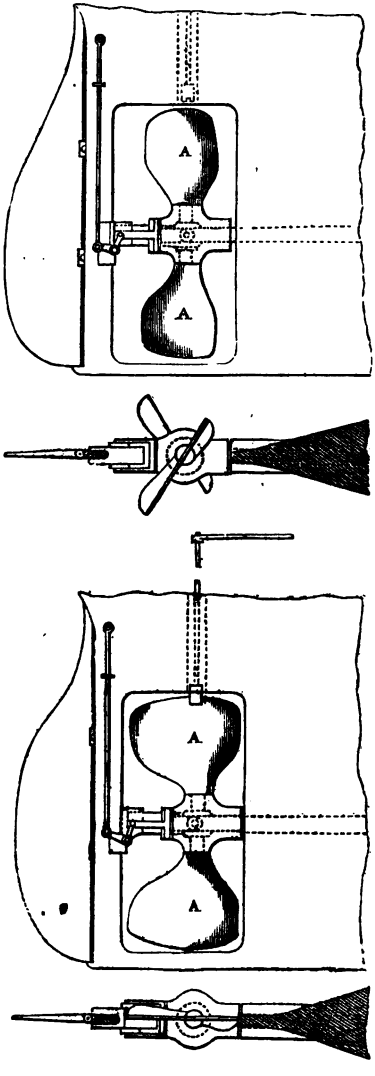
ing united to the axis by two or more arms. It is here represented. Both M. Carlsund and M. Sorenson of the Swedish navy are using a similar screw, but with the ring on the periphery or exterior of the blades. The blades and arms are segments of a screw, and there is nothing to prevent this being a most efficient propeller. It seems to continue in favour in America and in France; but the great objection to it in this country is, the difficulty of removing it, or preventing it from retarding the vessel when she is placed under canvas. Captain Ericsson at first used two of his propellers acting in combination, but he soon found that one was sufficient.

Maudslay's Feathering Screw.—This screw is represented in the following page. The object sought to be attained is, that the blades, whenever the vessel is put under canvas and the screw not required, should be placed in a direction parallel with the line of the keel, and so form as it were a portion of the dead wood, as they cause considerable obstruction if permitted to remain fixed in their position, or even though they be disconnected from the engine and allowed to revolve. In auxiliary sailing vessels not fitted with a trunk or aperture for the purpose of raising the screw out of the water, this is particularly valuable; but it will also be found useful in men-of-war, by lessening the width of the trunk through which it has to rise, if this be desired, and also by the facility which it gives, in emergencies, for placing a vessel quickly under canvas, or under steam, without requiring the aid of the crew, and also for placing the vessel under canvas when it may not be possible to keep the engines at work, from their having been injured by shot or any other cause, and when it may at the same time be imperative to keep the screw down in its

MAUDSLAY'S FEATHERING SCREW.

1st. In position for use as a Propeller.

2nd. In position for sailing under canvas alone.



place, to permit the stern guns to be used over the aperture of the trunk. The blades are locked in the vertical position by means of a catch and screw passing through the stern of the vessel, as shown in the woodcut.

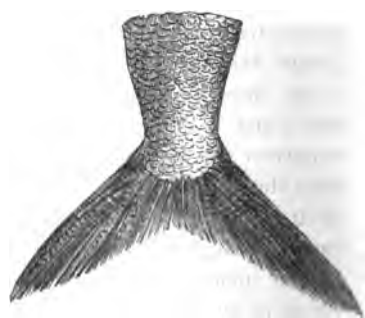
Hodgson's Parabolic Propeller. — This propeller is constructed with two blades, placed at an angle to the centre line of the axis, but differing essentially from the blades of a true screw, or of Woodcroft's screw, in their being hollow on the face, and being bent backwards in such a form as to be portions of a parabola. It is now much adopted in Holland. The peculiar principle of this propeller lies in this, that whereas the line of the action of other propellers upon the water is parallel to their axes, and the particles of water when driven off assume the form of a cone diverging as they recede; the water acted upon by the parabolic propeller, when driven off from each blade, is projected by the nature of the parabolic curve to its focus in the line of its axis. The water is therefore forced towards the centre, and exerts a greater amount of resistance from its not being so readily thrown up to the surface in the line of least resistance, where it escapes in the form of broken water.

Macintosh's Elastic Propeller.—This propeller is constructed with flexible blades of steel, in such a manner that, when made to revolve, the action of the water in pressing against them to propel the vessel, bends or springs their faces back, so as to make them approach nearer to a disc at right angles to its axis; and it is understood that Mr. Macintosh, if he could construct his blades to be so very flexible, would desire that they should be so bent as to assume this form when revolving at their highest velocity. In this case the propulsion of the vessel, instead of being obtained on the principle of the screw, may be looked upon as being obtained by the elastic spring or tendency of the blades to recover their form, thus keeping up a constant pressure upon the water behind them, and forcing the

vessel forward. The higher the velocity of revolution is, the more the blades will be bent back, and the greater will be their propelling force, until they assume the form of a disc, when any further velocity would cease to produce additional effect.

Comparison of the Flexible Propeller with the Action of a Fish.—The tails of three fishes—salmon, mackerel, and her-

ring—that swim at high velocities, are here represented; and, if the mode of their action be considered, it is conceived that it



will be seen to resemble that of Macintosh's propeller more than that of the Archimedean screw. When the tail of the fish is moved to the right, the web, or thin finny part, is bent to the left, on account of its weakness in comparison with the stronger parts near the body; and it is conceived that it is from the water pressing upon this oblique portion, while it keeps it bent back in opposition to the force exerted by the fish to send it to the right, that the motion is obtained.

In the Application of the Screw, fine After Lines are indispensable.—With regard to the application of the screw propeller, it is now well understood that the after lines of the vessel must be kept as fine as practicable just before the screw, the body of the vessel terminating, if possible, at the inner stern post, so as to avoid the flat surface, or "square tuck," which occasioned so much disquietude to our dockyard engineers upon the first introduction of this principle. It was then shown by experiment with the *Dwarf*, that the filling out of the lines immediately before the screw produced a most injurious effect upon the speed of the vessel; and those of the Admiralty screw steamers which have had their lines fined away there, have since advanced in speed by several knots an hour. The experiments recently tried on the *Flying-fish*, by attaching false after lines of great sharpness to her body, show that at high velocities her speed was advanced by this means about one knot per hour, although at low speed (as might be anticipated) the gain was not so apparent.

In wooden vessels, the edges of the screw aperture are strengthened with gun-metal castings, by means of which a sharper finish can be given to them. And it is chiefly in this point of view that iron vessels have shown themselves better adapted for the screw propeller than wooden ones, in consequence of the extreme fineness to which they may be tapered at the stern-post, with a due regard to strength.

Diameter of Screw.—The diameter of the screw should, in

most cases, be made as great as the draught of water will admit, and for running in smooth water its upper edge need not be more than a few inches beneath the surface. In the case of sea-going vessels, it is preferable to keep it 18 inches or 2 feet below the mean surface of the water.

Area of the Screw.—By the *area* of the disc of the screw is understood the area of the circle described by its extreme diameter. When the area of the blades is spoken of, their actual oblique surface should always be specially distinguished from the plane projection of the resisting surface. This latter measurement, as representing the actual amount of surface directly employed in the propulsion of the vessel, is probably the most important of these areas. The *Dwarf's* experiments show that the speed of this vessel gradually increased a little as the length of her screw was diminished from 2 feet 6 inches to 1 foot, the area corresponding to each length being 22·2 and 8·96 square feet respectively. It appears at first sight remarkable that so great a variation in the resisting surface should cause so little disturbance in the speed of the engines or of the vessel, thus showing very plainly how small a segment of the whole "pitch" is required to absorb all the power which the re-action of the water is capable of imparting. The fact seems to be, that the water in which the screw revolves acquires very soon the same rotatory motion with the screw, and as its resisting power is thus destroyed by the action of the *leading* part of the thread only, any additional length of screw, after the power has been absorbed, only retards by friction. The *Rattler's* experiments, conducted by the Engineering Department of H. M. Dockyard at Woolwich, were commenced with a screw 5 feet 9 inches long, which was gradually shortened, followed always by an improvement in the speed of the vessel, until it reached its present length of only 15 inches. The result of numerous experiments has led to the now very generally received opinion, that the length of the screw should be about one-sixth of its pitch.

Relative Value of Coarsely or Fine pitched Screws.—The question between the relative values of fine and coarsely pitched screws appears to be as yet quite undecided. The equally good results that have been obtained (more especially in the merchant service) by the use of coarsely pitched screws running at a comparatively low speed, and very finely pitched screws running at a great velocity, tend to the conclusion that a variation in pitch is not of much practical importance within certain limits.

Extent of Slip of the Screw.—The diameter of the screw and the speed at which it is driven, modify in a great measure the amount of slip, which is usually found to diminish in proportion as the diameter and velocity increase. Thus, the diameter of the *Rattler's* screw during her experiments was 10 feet, and the average slip 15 per cent., while the *Dwarf* and *Fairy*, with screws of between five and six feet diameter, showed an average slip of about 35 per cent. The slip is also affected by the form of the vessel's run and the manner in which the water closes in upon the screw, so that it is necessarily very uncertain, and will probably vary in every ship.

As the experiments made with the *Rattler* are probably the most extensive and valuable series of experiments on screw-propulsion which have yet been made, an epitome of the principal results obtained from them is here subjoined.

Dimensions of the Vessel.—The *Rattler* has the following dimensions, viz.—

	ft.	in.
Length between the perpendiculars	176	6
Length on keel	157	9½
Breadth of beam	32	8½
Depth in hold	18	7½
Burden in tons, builder's old measurement	888	0¾⁄₉₄
Mean draught of water during trials	11	3

Horses' power, 200; Maudslay, Sons, and Field, engineers.
Speed of the engines is multiplied by gearing 4 times, nearly.
The weight of ballast carried during the trials was 132 tons.
Ditto of coals 122 „

Experiments.—Feb. 3, 1844. With a two-threaded common screw, 9 feet diameter, 3 feet long, and 11 feet pitch, the vessel made 9·25 knots; the engines making 26·8 revolutions per minute, and the screw 106; slip, 19·5 per cent.

Feb. 9. With a three-threaded common screw of the same dimensions as the last, the speed of the vessel was reduced to 8·23 knots; the engines making 24·2 revolutions, and the screw 94·3; slip, 19·66 per cent.

Feb. 23. When the last screw was shortened to 1 foot 7½ inches, the vessel's speed increased to 8·57 knots; the engines making 24·8 revolutions, and the screw 98·4; slip, 19·7.

Feb. 28. With a two-threaded common screw, 10 feet diameter, 3 feet long, 11 feet pitch, the vessel made 8·958 knots; the engines making 24 revolutions, and the screw 95; slip, 13·8 per cent.

March 11. When the same screw was shortened to 2 feet, the vessel's speed increased to 9·448 knots; the engines making 25·5 revolutions, and the screw 107; slip, 13·5 per cent.

March 18. With a four-threaded common screw, 9 feet diameter, 1 foot 7 inches long, and 11 feet pitch, the vessel's speed was 9·18 knots; the engines making 26·3 revolutions, and the screw 104·4; slip, 27·7 per cent.

April 13. With a four-threaded Woodcroft's increasing pitch screw, of the same dimensions as the last, the pitch varying from 11 feet forward to 11 feet 6 inches aft, mean 11·275, the speed of the vessel was 8·159 knots; the engines making 24·15 revolutions, and the screw 96; slip, 23·5 per cent.

April 18. With the same screw as the last, but with two of the blades cut off, the vessel's speed advanced to 8·63 knots; the engines making 27·07 revolutions, and the screw, 107·5; slip, 25·97 per cent.

April 23. With Smith's or common screw (of cast brass), 9 feet diameter, 1 foot 2 inches long, and 11 feet pitch, three-

threaded, the vessel's speed was 9·88 knots; the engines making 27·39 revolutions, and the screw 108·4; slip, 15·97 per cent. Air quite calm.

June 13. With a common two-threaded screw, 10 feet diameter, 1 foot 6 inches long, and 11 feet pitch, the speed of the vessel was 9·811 knots; the engines making 27·92 revolutions per minute, and the screw 110·7; slip, 18·3 per cent.

June 27. The same screw as last, reduced in length to 1 foot 3 inches, gave a speed of 10·074 knots for the vessel; the engines making 26·19 revolutions, and the screw 103·97; slip, 10·42 per cent.

Note.—This is the most favourable result obtained during the experiments.

October 10. With Mr. Sunderland's propeller, 8 feet in diameter, the vessel's speed was 8·38 knots; the engines making 17·49 revolutions, and the screw-shaft 69·97.

October 12. With Mr. Steinman's propeller, 10 feet 1 inch diameter, the vessel's speed was 9·538 knots; the engines making 25·06 revolutions, and the propeller 104·24; the pitch 11 feet 6 inches; slip, 29·32 per cent.

October 17. With the common screw, 10 feet diameter, 11 feet pitch, 1 foot 3 inches long, the speed of the vessel was 9·893 knots; the engines making 27·03 revolutions, and the screw 108·12; slip, 15·65 per cent.

The experiments show, therefore, that the *common* screw, of the dimensions last quoted, gave a higher result than either Mr. Woodcroft's, Mr. Sunderland's, or Mr. Steinman's.

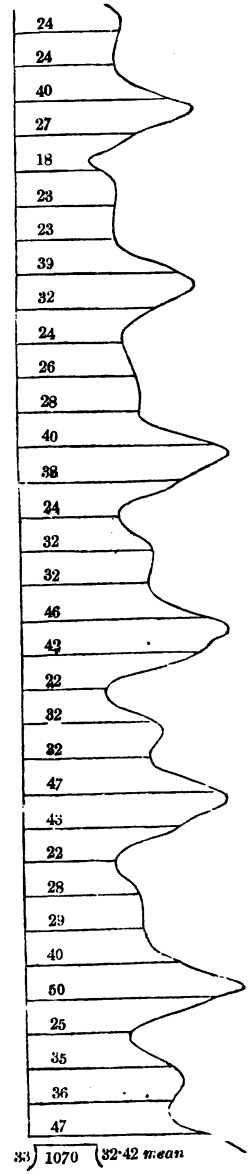
Thrust on the Dynamometer.—Experiments were made during the last three trials, to ascertain the actual thrust of the screw in propelling the ship, by observing the pressure on the spring of the dynamometer fitted to the end of the shaft. The results were as follows:—

October 15. With Sunderland's screw, the speed of the vessel being 8·346 knots, the pressure on the end of the shaft was 2·88 tons; the horse-power calculated by the dynamometer being 164·9, and by the indicator 320 horses—the ratio of the two powers being as 1 : 1·94. When the speed of the vessel was reduced to 6·698 knots, the pressure on the end of the shaft was 1·86 tons, equal to 85·85 horse power by the dynamometer, the indicator showing 173·2 H. P.

October 12. With Steinman's screw, the speed of the vessel being 9·537 knots, the pressure on the end of the screw shaft was 3·35 tons; the horse-power calculated by dynamometer being 219, and by indicator 452—the ratio of the two powers being as 1 : 2·7.

October 17. With the common screw, the speed of the vessel being 9·893 knots, the pressure on the end of the screw-shaft was 3·61 tons; the horse-power calculated by dynamometer being 245, and by indicator 465·6—the ratio of the two powers being as 1 : 1·9.

Loss of Speed by Expansion Gear.—Experiments were like-



Dynamometrical Figure taken from the Screw Shaft of the Rattler.

wise made with the expansion-gear of the *Rattler's* engines, to ascertain the loss of speed in the engines caused by applying successively each of the expansion cams. The stroke of the engines is 4 feet, and the slide valve was set to cut off one-quarter of the stroke, or one foot. The expansion cam has six steps, each cutting off four inches of the stroke; so that when the last step is working, the steam is expanded for three feet, or three-quarters of the stroke.

With the

1st	step of the cam,	the engine	made	25·2	double strokes per minute.
2nd	,,	,,		25·1	,, ,,
3rd	,,	,,		23·9	,, ,,
4th	,,	,,		23·4	,, ,,
5th	,,	,,		22·4	,, ,,
6th	,,	,,		21·3	,, ,,

Each of these experiments lasted five minutes, the mean being then taken.

Power consumed in driving her Machinery, per Indicator.—Another set of experiments were made with the indicator, to ascertain the amount of power consumed in driving the *Rattler's* machinery. The results were as follows:—

I. Without any gearing attached, the mean working pressure on the piston (taking the mean of both engines) was 1·1 lb. per square inch, the engines making 26 revolutions per minute, and the vacuum in the condenser being 28 inches.

II. With the gearing and screw shaft attached, but with the straps slack, the mean pressure was 1·67 lb., the engines making 25 revolutions, and vacuum in the condenser 28¼ inches.

III. With gearing and screw shaft attached, and straps tightened (but the screw not in gear), the mean pressure was 2·24 lbs., the engines making 25 revolutions, and the vacuum in the condenser 28¼ inches.

IV. With Woodcroft's four-threaded screw in gear, the mean working pressure indicated was 14·57 lbs., the engines making 24·85 revolutions.

V. With the three-threaded screw in gear, the mean working pressure indicated was 14·38 lbs., the engines making 26·2 revolutions.

The Dwarf's *Experiments.*—In connection with this subject there will be found at page 195 a Table of Experiments with Her Majesty's Steam Tender *Dwarf* (of 164 tons and 98-horses power), undertaken at Woolwich in the year 1845, to determine the best relative proportions for the screw propeller, with regard to *pitch*, *length*, and *area*. The whole of the screws used in these trials were true Archimedean screws. From this Table it appears that the most favourable results were obtained from a double-threaded screw of 5 feet 8 inches diameter, with a pitch of 8 feet, the length of segment being 18 inches, and the area 13·3 square feet; and it is remarkable that in the experiment following this, when the length of the screw has been reduced to 12 inches, and its area to 8·9 square feet, there is scarcely any appreciable variation in the resulting speed of the vessel or screw.

Tables of Screw Steamers and their Machinery.—Amongst the Tables at the end there will also be found

Tables of the Dimensions of Screw Steamers and their Machinery, in the Royal Navy.

Tables of the Principal Dimensions of Merchant Screw Steamers and their machinery.

Government Formula of Specification for Marine Steam Engines with Screw Propellers.

Tender to the Admiralty for Marine Engines, with Screw Propellers, of 450 horses' power.

Admiralty List of Tools and Spare Gear required with those Engines, etc. etc.

CHAPTER XIV.

REMARKS ON THE PRESENT POSITION OF THE SCREW AS A PROPELLER.

NOTWITHSTANDING the undoubted improvements which have of late years been effected in the application of the screw propeller, and the experience we have now had of its operation when applied to different descriptions of vessels under every variety of circumstance, the position which it holds, either as an antagonist to the paddle wheel or as a substitute for the sails of a ship, is still far from being well defined. For ships of the Royal Navy its superiority is so unquestionable that it were needless to raise any objections to it. In the merchant service, however, it has a harder battle to fight before it can wholly supplant the paddle wheel.

1. To begin with the class of full powered sea-going steamers, it seems that the paddle wheel is still the favourite on the majority of our mail routes, as on the West Indian and Transatlantic lines; while, on the other hand, the screw is supplanting its rival in the Mediterranean and Indian Ocean. When we consider that the directors of our various steamship companies have at their command the best engineering talent, and the greatest nautical experience, which the country can produce, as well as being themselves deeply interested in the determination arrived at, we may conclude that there is a reason for this diversity of opinion; the probable explanation being, that the screw is found to perform best in the comparatively smooth seas of the Mediterranean and the Indian Ocean, and the paddle wheel best in the long swell and boisterous weather of the Atlantic.

The worst feature of the paddle wheel in this class of vessel is, the great variation in the dip, as the coals are expended,

steam or horses. The disturbance is much increased in passing through shallow water, when the boat is said to "drag the bottom," a large proportion of the engine power being then uselessly expended in displacing the water.

With regard to that anomaly, the *Great Eastern*, we anticipate an engineering triumph and a commercial failure.

By referring to the Table at page 210 in the Appendix (the materials for compiling which have been kindly supplied by Captain Ramsey, R.N., Admiralty Superintendent of Mail Packets at Southampton), we are enabled to compare at a glance the actual performance of some of the best and largest screw and paddle steamers afloat; the average speed of each vessel during her outward and homeward voyage being given, as well as the knots run by each steamer for one ton of coals consumed. These results show a great economy in the consumption of fuel in favour of the screw steamers of the Peninsular and Oriental Company, when compared with the paddle steamers of the Royal Mail Company, but it must be remembered that the latter are larger and heavier vessels, of greater displacement and carrying powers. The number of knots run for each ton of coals (as given in the Table) being irrespective alike of displacement and speed, an allowance must be made for these essential conditions, in comparing results of different steamers. It is interesting to observe how well the formula, that "the speed varies as the cube root of the power" (or consumption of fuel), is fulfilled in practice.

APPENDIX.

TABLE No. I.

ADMIRALTY FORMULA OF SPECIFICATION FOR MARINE ENGINES, WITH PADDLE WHEELS.

SPECIFICATION *of certain Particulars to be* strictly *observed in the construction of a pair of Marine Steam-Engines with Paddle Wheels, referred to in the Admiralty Letter on Her Majesty's Service.* 1845.

The tenders are to be made (in triplicate) on the accompanying printed forms, *every particular in which is to be strictly and carefully filled up;* and all drawings, models, and boxes containing them are to be distinctly marked with the names of the parties transmitting them.

The whole weight of each pair of engines, including the boilers (with the water in them), the coal boxes, the paddle wheels, the spare gear, the floor plates, ladders, guard rails, and *all other articles* to be supplied under the contract, is not to exceed 190 tons.

The coal boxes (in the space of the engine room) are to contain eight days' coal, computed at 8 lbs. per horse-power per hour, and at 48 cubic feet to the ton. Sufficient details of the coal boxes are to be shown in the drawing to enable a computation of their contents to be made. In this computation the space below the deck to the depth of six inches is to be excluded, to allow for the space occupied by the beams, and for the difficulty of completely filling the boxes with coals.

To avoid the possibility of mistake in the dimensions given in the drawings furnished to the respective parties, it is to be understood that—

The length of the engine room, in the clear, is not to exceed	48 ft. 0 in.
Breadth of ditto	As shown in the drawing.
Depth of ditto	
The centre of the shaft above the water line	

The situation of ditto, as per drawing, or as near as can be.

The holding-down bolts are to be secured by nuts let into the sleepers, so as not to require the bolts to pass through the vessel's bottom; and the bolts are to have, at the lower end of their points, wrought-iron washers about eight inches square, and one inch thick, placed between the nuts and the wood. Should this mode of security be inapplicable to the particular kind of engine proposed, the engineer is fully to describe any other secure mode which he may think the most advisable to adopt.

The pistons are to be fitted with metallic packings.

The blow-off pipes are to be not less than $3\frac{1}{2}$ inches in diameter, and their thickness not to be less than $\frac{1}{4}$ inch.

The thickness of the steam pipes is not to be less than $\frac{1}{4}$ inch; of the bilge pipes, not less than $\frac{1}{4}$ inch; of the feed pipes, not less than $\frac{1}{8}$ inch; of the waste-steam pipe, not less than $\frac{1}{8}$ inch; and of the waste-water pipes (if of copper), not less than $\frac{1}{4}$ inch.

The cylinders are to be fitted with discharge or escape valves at the top and at the bottom of each, for allowing of the escape of water therefrom; the valves to have suitable metallic cases, to obviate the danger of persons being scalded by any escape of boiling water. Reverse valves are to be fitted to the boilers.

Each cylinder is likewise to be fitted with a separate movement and valve, for the purpose of using the steam expansively in various degrees, as may from time to time be found eligible.

The air pumps are to be lined with gun metal of half an inch in thickness, when finished.

The air-pump buckets are to be of gun metal, with packing rings.

The air-pump rods are to be of gun metal, of Muntz's metal, or of wrought iron cased with gun metal.

The threads of all screwed bolts, nuts, and pins used in engines and boilers, and in every other part of the work furnished by the contractor, are to agree with the threads used in the steam department at Woolwich.

A small engine is to be fitted, capable of working one of the pumps for feeding the boilers.

Pipes to be fitted for supplying, in the event of a leak in the vessel, the requisite quantity of water from the bilge to the condensers.

The hand pump to be made capable of being worked by the engine also, and to be arranged to pump into the boilers, on deck, or overboard; and to draw water from the boilers, from the bilge, or from the sea.

The feed apparatus to be complete, independently of any feed from a cistern above the deck, should such be fitted.

The steam pipes and *all* other pipes to be of copper, and their respective diameters to be specified in the tender.

A separate damper to be fitted to every boiler, and dampers to be fitted to the fronts of the ash pits.

Brine pumps, or some other equally efficient apparatus, with refrigerators, to be fitted to the boilers.

A small flat iron vessel to be fixed in one of the paddle boxes, with two pipes, one communicating with the stoke-hole, and the other with the boiler, for obtaining a small supply of distilled water from the boiler. Air tubes to be fixed in the coal boxes, for ascertaining their temperature. Particulars will be furnished to the contractors, on application to the captain superintendent at Woolwich Dockyard.

The boilers are to be tubular, having iron tubes of $2\frac{1}{2}$ or 3 inches outside diameter; and it is desirable that the upper part should not be a greater distance above the water line than circumstances render necessary. They are to be constructed in three or more separate parts, each of which may be used independently of the others. Sufficient details of the boilers are to be shown, to enable a calculation to be made of the area of fire grate, and of the fire and flue surface.

In the manufacture of tubular boilers, care is to be taken to leave sufficient room between the crowns and the lowest row of tubes, with mud-hole doors in the front of each boiler, to admit a person into these parts, both for the purpose of cleaning them and of repairing them, without taking out the tubes. All mud-hole doors to be placed on the *inside* of the boilers.

A space of 13 inches wide is to be left clear between the boilers and the coal boxes in every part. The boilers are to be placed on a bed of mastic.

The paddle wheels are to be of the common construction, and to be fitted with suitable brakes. Braithwaite's disconnecting apparatus is also to be applied.

The power of the engines is to be 260 horses, calculated at 7 lbs. effective pressure on each square inch of the piston, and the speed of the piston

ft.	in.			
for 4	0	stroke not to exceed	196	feet per minute.
4	6	ditto . . .	204	,,
5	0	ditto . . .	210	,,
5	6	ditto . . .	216	,,
6	0	ditto . . .	222	,,
6	6	ditto . . .	226	,,
7	0	ditto . . .	231	,,
7	6	ditto . . .	236	,,
8	0	ditto . . .	240	,,

All the necessary ladders for the engine room, together with fenders, guard rails, and floor plates, are to be included in the tender, and likewise the expense of *trying and fitting* the spare gear.

The expense of clothing (in the following manner) the cylinders, steam pipes, and boilers is also to be included in the tender.

The cylinders are to be covered with hair felt to the thickness of two inches. The felt is to be covered with thoroughly dried wood, and bound together by iron or brass hoops.

The steam pipes are to be clothed with felt, which is to be woulded with spun yarn, and then to be covered with canvas; the whole to be of such thickness as to be even with the flanges.

After it has been ascertained by trial that every part of the boilers is perfectly tight, two good coats of red-lead paint are to be then put on them, and felt applied to the tops, sides, and ends, to the thickness of two inches, while the paint is moist. For the more convenient application of the felt, it is to be previously stitched to canvas for the purpose of holding it together. The canvas is then to be well painted, and carefully covered with thoroughly dried one-inch deal boards having rabbeted or grooved and tongued joints, and bound up to the boilers by suitable iron straps.

The coating of felt and boards on the top of the boilers or steam chest is to be kept at least 18 inches from the funnel, and the circular space between the coating and the funnel is to be covered with a three-inch course of brick, set in cement, and surrounded and held together by an iron hoop, or this space may be filled up with mastic.

The boards and bricks on the upper parts of the boilers are to be covered with sheet lead, 4 pounds to the square foot, so as to prevent any leaks from the deck reaching the felt.

N.B. Parties contracting to supply machinery for Her Majesty's ships and vessels are to be bound in a penalty of one thousand pounds to complete their contracts at the stipulated periods; and it is distinctly to be understood, that it is their Lordships' intention to enforce the bond in all cases where the machinery is not fixed and ready for trial at the time specified in the contract.

The time required for completing the machinery so as to be ready to be put on board the vessel, is to be considered as commencing from the date of their Lordships' acceptance of the tender.

And the period stipulated for fixing the machinery on board the vessel is to be calculated from the date the vessel is placed in the hands of the parties for that purpose.

It is likewise to be understood that, if the weight specified in the tender be exceeded, the contractor is to forfeit one thousand pounds, or their Lordships are to be at liberty to reject the engines, the manufacturers paying one thousand pounds for the disappointment.

It is to be understood that the practice of fixing new engines on board Her Majesty's vessels at Woolwich Dockyard is to be *entirely discontinued.* The ports to which their Lordships will, for the convenience of manufacturers, allow vessels to be taken,

are those of London, Liverpool, Greenock, Glasgow, and Dundee, provided *the places* at which the vessels are to lie in those ports shall be named in the tender, and approved of by their Lordships.

In all cases of vessels receiving their engines on board at any other port than that of London, a deduction of two per cent. will be made from the price of the engines named in the tender, as a compensation for the expense, wear and tear, and risk thereby incurred.

No charge will be allowed for transporting the vessel to the place where the engines are to be fixed on board; for coals in trying the engines *until they are complete;* for boats, anchors, men, lighters, pilotage, canal or dock dues, shipwrights' work, or for any other expense whatever. The "watching" of vessels is to be performed in future by officers and men in Her Majesty's service.

TENDER *from* *for a pair of Steam Engines with Paddle Wheels, pursuant to a Letter from the Admiralty, dated , and the Specification accompanying the same.*

Collective power of the two engines	260 horses.
Weight of the engines	80 tons.
„ Boilers and their apparatus	45 „
„ Water in boilers	30 „
„ Coal boxes	10 „
„ Paddle wheels	13 „
„ Spare gear, and all fittings included in contract	12 „
Total weight	190 tons.

	ft. in.
Diameter of cylinders	0 61½
Length of stroke	4 6
Strokes per minute	No., 24.
Diameter of paddle wheels	21 0
Breadth of ditto	8 3
Diameter of necks of intermediate and paddle-wheel shafts	0 12½
Quantity of coals which can be stowed in the coal boxes	185 tons, or 8½ days' consumption.
Estimated consumption of coals per horse per hour	8 lb.

Cost of engines, boilers, and coal boxes	£11,090	Including the erection on board.
Ditto paddle wheels, common	800	
Cost of duplicate and spare articles, as per list	850	Including the entire fitting and trying of the same wherever and whenever required.
Total cost	£12,740	

Including all the items of expense mentioned at the end of the specification.

Time required for completing the work ready to be put on board—for one pair, eight months; for two pairs, nine months.

Further time required for fixing the whole in the vessel, ready for service, two months. The engines to be fixed on board in the East India Docks, London.

The boilers will be constructed on the tubular principle, embodying all the latest improvements. The tubes will be of iron, 3 in. external diameter and 6 feet long, and secured in the best manner in tube plates of the best charcoal iron, $\frac{3}{4}$-inch thick. The bottoms of the boilers will be composed of plates $\frac{7}{16}$-inch thick; the sides and tops of plates $\frac{5}{8}$-inch thick; and the fire boxes, of Lowmoor plates, $\frac{3}{8}$-inch thick. The heating surfaces of the proposed boilers will be—grate-bar surface, 85 square inches per horse-power; *total* tube and flue surface, 16 square feet per horse, and *effective* surface, $13\frac{1}{2}$ square feet. Sufficient room will be left between the crowns of the furnaces and the tubes for cleaning the former. Each boiler will be fitted with separate safety valve and stop valve, so that either may be worked distinct from the other if required. Brine pumps will be attached to the boilers; also a small feeding engine will be provided for working the supplementary feed pump.

The boilers will be clothed with felt, wood, and lead, as usual.

The blow-off pipes will be of copper, $3\frac{1}{2}$ inches diameter, and $\frac{1}{4}$ inch thick, having their cocks, conical pipes, and stop valves of gun-metal.

The engines will be constructed on the direct action principle, as shown by the drawings, and will embody all the latest improvements. The slide valves will be formed on the long D construction. The air pumps will be of solid gun-metal; and the air-pump rod and bucket, foot valve, and delivery valve, will be all of gun-metal.

There will be two feed and two bilge plunger pumps, each pump capable of supplying both the boilers.

The pistons to be of the most approved construction, with metallic packing. The steam pipes, feed pipes, and all other pipes usually constructed of copper will be of this material, of sufficient thickness. All the bearings will be of best brass. Expansive gear will be attached to the engines. The framings of the engines will be composed chiefly of wrought iron, and will be made as light as is consistent with the requisite strength.

The paddle wheels will be on the common construction; and the shaft will run through to an outside bearing on the spring beam.

The whole to be of the best material and workmanship.

List of Tools and Spare Articles for Paddle-wheel Engines of Horses Power.

ENGINEERS' TOOLS.

	No.
Brushes, for boiler tubes, to every 100-horse power	20
Drifts, short and long do. do.	1 each.
Fire irons	12
Mandrils do. do.	1 each.
Scrapers, circular and forked do.	5 each.
Spanners and wrenches of sorts	24
Stocks, taps, and dies, from ¼ inch to 1¼ inch	1 set.

SPARE GEAR.

Air-pump side rods, with straps and brasses complete (if so fitted)	2
Air-pump rod	1
Air-pump cross head (if so fitted)	1
Arms for paddle wheels	4
Bars, furnace	½ set.
Bearers	3
(Beam, sway (if so fitted)	1)
Boiler plates	6 cwt.
Bolts and nuts for engines, properly assorted	120
Bolts and nuts for paddle wheels, or rivets instead (if so fitted)	100
Bolts and nuts, hook, for paddle boards	100
Brasses for outer end of shaft	2
(Cylinder side rods, with straps and brasses complete (if so fitted)	2)
Cylinder lid	1
Cylinder cross head (if so fitted)	1
Ferrules for boiler tubes, to every 100-horse power	50
(Fork head (if so fitted)	1)
(Side links to fork head, with straps and brasses complete (if so fitted)	2)
Paddle boards	12
Paddle plates	18
Piston and rod	1
Rod, connecting, with strap and brasses, complete	1
,, Parallel motion, with brasses complete, for one engine	1 set.
,, Feed pump (if so fitted)	1
,, Bilge (if so fitted)	1
,, Slide	1
Screws, packing, for slide, complete for one engine	1 set.
Segments for paddle wheels, large	4
Segments for paddle wheels, small (if so fitted)	2

Springs for each piston (if so fitted)	1 set.
Springs for other parts of engines, for 1 engine . .	1 set.
Tubes, boiler, to every 100-horse power . . .	10
Tubes, glass, for barometers	2
Tubes, glass, for boilers	4
Valve, foot, without seat	1
Washers, iron	100

NOTE.—Such articles contained in this list as are not to be found in the particular kind of engine tendered for, to be struck out by the party tendering; and any articles may be added to it which, from the construction of the engines, he may consider ought to be supplied.

TABLE No. II.

ADMIRALTY FORMULA OF SPECIFICATION FOR MARINE ENGINES, WITH SCREW PROPELLERS.

SPECIFICATION *of certain Particulars to be* strictly *observed in the construction of Marine Steam Engines (with Screw Propellers,) referred to in the Admiralty Letter of the 9th of September*, 1845, *for Her Majesty's Steam Guardship of 72 Guns, with Auxiliary Engines of 450-Horse Power.*

The tenders are to be made (in triplicate) on the accompanying printed forms, *every particular in which is to be carefully and strictly filled up;* and all drawings, models, and boxes containing them are to be distinctly marked with the names of the parties transmitting them.

The coal boxes (in the space of the engine room) are to contain as much room as possible. The arrangement and quantity (computed at 48 cubic feet to the ton) to be shown in the tender.

The consumption of coal per horse-power, and the *number of days'* coals which the boxes will contain, are to be accurately stated in the tender.

The breadth and depth of the engine room are shown in the drawing. If the length should be found insufficient, the *foremost* bulkhead may be removed as much further forward as is necessary; but the situation of the *after* bulkhead is not to be altered.

As the engines will not be so frequently worked as in an ordinary steam vessel, especial care is to be taken in the arrangement of the boilers and machinery, that every part may be easily acces-

sible, so that no difficulty may be found in preserving them in an efficient state.

The situation of the centre of gravity of the whole machinery, coals, etc., to be shown in the drawing.

The pistons are to be fitted with metallic packings.

The blow-off pipes are to be at least 3½ inches in diameter, and their thickness not to be less than ½ inch.

The thickness of the steam pipes is not to be less than ½ inch; of the bilge pipes, not less than ½ inch; of the feed pipes, not less than ⅜ inch; of the waste-steam pipe, not less than ⅜ inch; and of the waste-water pipes (if of copper), not less than ½ inch.

The cylinders are to be fitted with discharge or escape valves at the top and at the bottom of each, for allowing of the escape of water therefrom; the valves to have suitable metallic cases, to obviate the danger of persons being scalded by any escape of boiling water. Reverse valves are to be fitted to the boilers, and efficient stop valves at the ship's side to the waste-water pipes.

Each cylinder is likewise to be fitted with a separate movement and valve for the purpose of using the steam expansively in various degrees, as may from time to time be found eligible.

The air pumps are to be lined with gun metal, of half an inch in thickness, when finished.

The air-pump buckets are to be of gun metal, with packing rings.

The air-pump rods are to be of gun metal, Muntz's metal, or of wrought iron cased with gun metal.

The threads of all screwed bolts, nuts, and pins used in the engines and boilers, and in every other part of the work furnished by the contractor, are to agree with the threads used in the steam department at Woolwich.

A fan-blower with all the necessary apparatus, is to be provided for blowing the fires in the event of injury to the funnel; and a small engine is to be fitted, capable of working the blower as well as one of the pumps for feeding the boilers.

Pipes to be fitted for supplying, in the event of a leak in the vessel, the requisite quantity of water from the bilge to the condensers.

The hand pump to be made capable of being worked by the engine also, and to be arranged to pump into the boilers, on deck, or overboard; and to draw water from the boilers, from the bilge, or from the sea.

The steam pipes and *all* other pipes to be of copper, and their respective diameters to be specified in the tender.

A separate damper to be fitted to every boiler, and dampers to be fitted to the fronts of the ash pits.

Brine pumps, or some other equally efficient apparatus, with refrigerators, to be fitted to the boilers; and blow-off pipes so arranged that any boiler may be blown off separately.

Air tubes to be fixed in the coal boxes, for ascertaining their temperature. Particulars of these and other small fittings, such as glass water gauges, etc., to which the contractors will be required to conform, will be furnished to the contractors on application to the captain superintendent at Woolwich Dockyard.

The boilers are to be of the tubular construction, having tubes of $2\frac{1}{2}$ or 3 inches diameter outside; the cost with iron and with brass tubes respectively is to be specified in the tender.

The boilers are to be constructed in three or more separate parts, each of which may be used independently of the others. Sufficient details of the boilers are to be shown to enable a calculation to be made of the area of fire grate and of the fire and flue surface.

In the manufacture of tubular boilers, care is to be taken to leave sufficient room between the crowns and the lowest row of tubes, with mud-hole doors in the front of each boiler, to admit a person into these parts, both for the purpose of cleaning them and of repairing them, without taking out the tubes.

A space of thirteen inches wide is to be left clear between the boilers and the coal boxes in every part. The boilers are to be placed on a bed of mastic.

The power of the engines to be 450 horses; and the weight, if possible, not to exceed 300 tons; the power to be calculated at 7 lbs. effective pressure on every square inch of the pistons, and at 45 strokes per minute.

The whole of the machinery and boilers to be below the lower or sleeping deck.

The speed of the propeller shaft to be at least 45 revolutions per minute, the shaft to be driven direct from the engines.

The screw propeller to be two-threaded, and to be made of gun metal, of about 15 feet 6 inches in diameter, and of the form to be hereafter determined.

The screw to be hung upon a separate shaft, capable of being easily disengaged from the driving shaft; and suitable means are to be provided for shipping and unshipping it through a trunk extending from the upper part of the aperture for the screw to the upper deck.

It is to be understood that any plans in which the arrangements may differ from those above described will be taken into consideration, if they shall appear likely to answer.

All the necessary ladders for the engine room, together with fenders, guard rails, and floor plates are to be included in the tender, and likewise the expense of *trying and fitting* the spare gear.

The expense of clothing (in the following manner) the cylinders, steam pipes, and boilers, is also to be included in the tender.

The cylinders are to be covered with hair felt to the thick-

ness of two inches; the felt is to be covered with thoroughly dried wood, well fitted, and bound together by iron or brass hoops.

The steam pipes are to be clothed with felt, which is to be woulded with spun yarn, and then to be covered with canvas; the whole to be of such thickness as to be even with the flanges.

After it has been ascertained by trial that every part of the boilers is perfectly tight, two good coats of red-lead paint are to be then put on them, and felt applied to the tops, sides, and ends, to the thickness of two inches, while the paint is moist. For the more convenient application of the felt, it is to be previously stitched to canvas for the purpose of holding it together. The canvas is then to be well painted, and carefully covered with thoroughly dried one-inch deal boards having rabbeted or grooved and tongued joints, and bound up to the boilers by suitable iron straps.

The coating of felt and boards on the top of the boilers or steam chest is to be kept at least 18 inches from the funnel, and the circular space between the coating and the funnel is to be covered with a three-inch course of brick, set in cement, and surrounded and held together by an iron hoop, or this space may be filled up with mastic.

The boards and bricks on the upper parts of the boilers are to be covered with sheet lead, 4 pounds to the square foot, so as to prevent any leaks from the deck reaching the felt.

The engines to be fitted on board the ships either in the Thames, at Portsmouth, or Plymouth; the parties tendering to state the expense of fixing the machinery at each place respectively, it being understood that if fixed in the Thames, dock dues and all other expenses are to be borne by the contractors. But if at Portsmouth or Plymouth Dockyards, the use of the Government shears or cranes, with the necessary hands, will be allowed for lifting the heavy weights.

N.B. The time required for completing the machinery so as to be ready to be put on board the vessel, is to be considered as commencing from the date of their Lordship's acceptance of the tender.

And the period stipulated for fixing the machinery on board the vessel, is to be calculated from the date the vessel is placed in the hands of the parties for that purpose.

Parties contracting to supply machinery for Her Majesty's ships and vessels, are to be bound in a penalty of one thousand pounds to complete their contracts at the stipulated periods, and it is distinctly to be understood, that it is their Lordships' intention to enforce the bond in all cases where the machinery is not fixed and ready for trial at the time specified in the contract.

It is likewise to be understood that, if the weight specified in the tender be exceeded, the contractor is to forfeit one thousand

pounds, or their Lordships are to be at liberty to reject the engines, the manufacturers paying one thousand pounds for the disappointment.

TENDER *from* *for a pair of Steam-Engines (with Screw Propellers), pursuant to a Letter from the Admiralty, dated the 9th of September*, 1845, *and the Specification accompanying the same. For a 72-Gun Steam Guard Ship (auxiliary).*

N.B. All the following particulars are to be carefully stated in this paper, so far as may relate to the tender required by the Admiralty.

		In words and figures.
Collective power of the two engines		four hundred and fifty horses 450.
The centre of gravity of the sum of these weights is to be clearly stated in the drawing.	Weight of engines . .	127 tons. One hundred and twenty-seven.
	Do. Boilers and their apparatus	55 „ Fifty-five.
	Do. Water in the boilers	45 „ Forty-five.
	Do. Coal-boxes . .	15 „ Fifteen.
	Do. Propeller, propeller shaft, and machinery for driving it	30 „ Thirty.
	Do. Spare gear, and all fittings included in contract	18 „ Eighteen.
	Total weight	290 tons. Two hundred and ninety.

Diameter of cylinders	four, each 50 in.	
Length of stroke	3 ft. 0 in.	
Strokes per minute . . .	No., 45	
Revolutions of propeller shaft per minute	No., 45	
Diameter of the necks of the engine shaft	. . . . . 13 in.	
Do. Propeller shaft	. . . . . 13 in.	
The quantity of coal which can be stowed in the coal boxes	250 tons, being 9 days' consumption.	
Estimated consumption of coals per horse power per hour	. . . . . 6 lbs.	
Cost of engines, boilers and coal boxes	£17,620	Including the erection on board.
Do. Propeller, shafts, and all machinery connected with them	3,650	

Cost of Duplicate and spare articles as per enclosed list, and all fittings and other articles to be supplied under the contract	£1,450	Including the entire fitting and trying of the same wherever and whenever required, and all the other items of expense mentioned at the end of the specification.
Total cost . . .	£22,720	
Time required for completing the work ready to be put on board	12 months	
Further time required for fixing the whole in the vessel, so as to be fit for service	3 months	

At what place the engines are to be fixed on board.

The construction and dimensions of the boilers to be here described, and the thickness of the plates of the various parts of them, and if the boilers be tubular, the diameter and length of the tubes to be specified, as well as the material of which they are to be composed.

Boilers to be tubular; over all, 19 ft. 9 in. long, 24 ft. wide, and 12 ft. high; being kept (as well as the engine) entirely under the orlop deck. Heating surface to be 15 sq. ft. per horse-power, and grate-bar surface, 80 sq. in. per horse.

Engines to have four horizontal cylinders, driving the screw shaft direct.

The blow-off pipes to be 4 inches in diameter and ¼ inch thick, of *copper;* having their cocks, conical pipes, and stop valves of *gun-metal.*

The whole to be of the best material and best workmanship.

N.B. The position of the engines, propeller, boilers, and coal-boxes to be distinctly shown in the accompanying drawings of the engine room.

LIST *of* TOOLS *and* SPARE ARTICLES *for Engines (with Screw Propellers) of* 450 *Horses' Power.*

ENGINEERS' TOOLS.

	No.
Brushes, for boiler tubes, to every 100-horse power .	20
Drifts, short and long do. do. .	1 each.
Fire irons	12
Mandrils do. do. .	1 each.
Scrapers, circular and forked, do. do. .	5 each.
Spanners and wrenchers, of sorts	24
Stocks, taps, and dies, from ¼ inch to 1¼ inch. . .	1 set.

SPARE GEAR.

Air-pump side rods, with straps and brasses complete (if so fitted)	No. 2
Air-pump rod	1
Air-pump cross head (if so fitted)	1
Bars, furnace	½ set.
Bearers	3
Boiler plates	6 cwt.
Bolts and nuts for engines, properly assorted	120
Cylinder lid	1
Cylinder cross head (if so fitted)	1
Ferules for boiler tubes, to every 100-horse power	50
Piston and rod	1
Propeller and shaft complete	1
Rod, connecting, with strap and brasses complete	1
„ Feed pump (if so fitted)	1
„ Bilge pump (if so fitted)	1
„ Slide	1
Screws, packing, for slides, complete for one engine	1 set.
Springs for each piston (if so fitted)	1 set.
Springs for other parts of engines, for 1 engine	1 set.
Tubes, boiler, to every 100-horse power	10
Tubes, glass, for barometers	2
Valve, foot, without seat	1
Washers, iron	100

NOTE.—Such articles contained in this list as are not to be found in the particular kind of engine tendered for, are to be struck out by the party tendering; and any articles may be added to it which, from the construction of the engines and propeller machinery, he may consider ought to be supplied.

TABLE No. III.

TABLE OF EXPERIMENTS WITH H. M. SCREW STEAM-TENDER, "DWARF."

Burthen in tons, 163 ⅔. Nominal horse power, 90. Draught of water, 7 feet aft; 5 feet 10 inches forward. Fitted with a common two-threaded screw, 5 feet 1 inch in diameter, with common pitch.

No of Experiments.	Pitch of the Screw.	Length of the Screw.		Area of the Screw.	Average revolutions of the engines per min.	Average revolutions of the screw per min.	Proportion of revolutions of screw to engine.		Average pressure at the end of shafts, indicated by the Dynamometer.	Speed of the screw per hour.	Slip of the screw per hour.	Speed of the Vessel per hour.	Gross average power exerted in the cylinders.	Speed of the Vessel computed as if the power exerted had been (90 horses.	Average power expended in propelling, by Dynamometer.	Ratio of gross indicator to Dynamometer power.
	feet.	ft.	in.	sq. f.					tons.	knots		knts.	horses.	knots.	horses.	
1	8·0	2	6	22·2	28·8	146·2	5	16 1	1·36	11·53	25·0	8·65	130·7	9·28	81·0	1·62
2	,,	2	0	17·8	29·6	152·7	,,		1·49	12·06	25·7	8·95	151·5	9·12	92·1	1·65
3	,,	1	6	13·3	30·1	155·4	,,		1·42	12·26	27·1	8·94	137·0	9·41	87·3	1·57
4	,,	1	0	8·9	32·2	166·0	,,		1·51	13·09	30·4	9·11	168·8	8·95	95·1	1·78
5	10.32	1	8 1/16	13·3	31·8	127·1	4	1	1·07	12·93	33·4	8·60	148·7	8·82	63·5	2·33
6	,,	2	3½	17·8	30·8	123·3	,,		·96	12·55	30·8	8·74	136·3	9·22	57·6	2·34
7	,,	1	1½	8·9	34·9	139·7	,,		1·00	14·22	36·4	9·05	154·0	9·16	62·6	2·44
8	,,	2	10 1/16	22·2	30·9	123·6	,,		·91	12·57	29·3	8·89	143·8	9·21	55·9	2·57
9	18·23	1	10 9/16	13·3	36·6	114·2	3	15 1	1·17	14·90	40·4	8·88	161·7	8·85	71·6	2·25
10	,,	3	0 1/16	22·2	34·0	106·6	,,		1·35	13·90	38·7	8·52	149·5	8·72	79·4	1·9
11	,,	1	¼	8·9	40·2	125·9	,,		1·74	16·42	44·7	9·07	176·9	8·77	108·5	1·62
12	,,	2	1 1/16	17·8	35·7	111·8	,,		1·74	14·58	39·5	8·83	166·4	8·71	105·9	1·57
13	,,	2		17·8	26·2	105·7	4	1	1·78	13·79	33·9	8·29	151·9	8·48	101·6	1·49
44	,,	3	¼	22·2	25·4	101·6	,,		1·78	13·52	39·5	8·01	139·6	8·52	95·4	1·47
15	,,	1	10 9/16	13·3	26 0	104·1	,,		1·69	13·58	41·7	7·92	117·2	8·79	92·0	1·27
16	,,	1	3 1/16	9·9	29·8	119·3	,,		1·98	15·57	46·1	8·38	147·4	8·61	110·6	1·32
17	,,	1	3 1/16	8·9	21·6	111·7	5	16 1	1·64	14·58	46·1	7·85	116·6	8·78	88·8	1·31
18	,,	1	10 9/16	13·3	19·9	102·6	,,		1·62	13·39	42·9	7·64	114 2	8·55	85·4	1·34
19	,,	2	6 1/16	17·2	19·0	97·9	,,		1·73	12·78	41·1	7·52	111·5	8·48	89·6	1·23
20	,,	3	1½	22 2	18·5	95·4	,,		1·71	12·45	39·5	7·52	108·8	8·56	88·5	1·22
21	10 32	2	10½	22·2	22·5	116·2	,,		1·99	11·82	30·0	8·28	127·3	8·94	113·4	1·12
22	,,	1	8 1/16	13·3	24·9	128·4	,,		1·91	13·06	36·4	8·39	154·0	8·81	109·3	1·28
23	,,	1	1½	8·9	26·6	137·5	,,		1·99	14·0	38·5	8·61	138·5	9·03	113·1	1·17
24	,,	2	3½	17·8	23·9	123·1	,,		1·94	12·53	32·9	8·40	126·6	9·08	112·3	1·13

These experiments were made at Woolwich during the months of June, July August, 1845. The following are the dimensions of the *Dwarf*, viz.—

	ft.	in.
Length between the Perpendiculars . . .	130	0
Breadth extreme	16	6
Depth in Engine-room	15	9
Diameter of Cylinders	3	4
Length of Stroke	2	8

TABLE OF SCREW STEAMERS

(Compiled by the Engineering Department

1.—

	Name of the Vessel.	Length between the Perpendiculars.	Breadth, extreme.	Mean draught at the time of trial.	Area of immersed midship section.	Displacement at time of trial.	Tonnage—Builder's old measurement.	Horses' power, Nominal.	Horses' power indicated at trial.
		ft. in.	ft. in.	ft. in.	sq. ft.	Tons.	Tons.	H. P.	H. P.
1	Ajax	176 0	48 6½	22 6½	807	3090	1761	450	846
2	Amphion	177 0	43 2	19 0	546	2025	1474	300	592
3	Archer	180 0	33 0	14 1	372	1238	970	200	345
4	Arrogant	200 0	45 8¾	18 10½	580	2444	1872	360	623
5	Bee	63 0	12 2	3 5½	28·2	33·2	43	10	
6	Blenheim	181 2¾	48 6	21 1½	738	2790	1832	450	938
7	Brisk	193 7	35 0	13 9	373	1474	1074	250	
8	Conflict	192 6	34 4	14 6	402	1443	1038	400	777
9	Dauntless	210 0	39 9	16 4	522	2340	1479	580	811
10	Ditto, lengthened at the stern	218 1				2251	1569	,,	1218
11	Desperate	192 6	34 4	15 9	443	1628	1037	400	
12	Dwarf (iron)	130 0	16 6	5 6	44	98	164	90	216
13	Encounter	190 0	33 2	11 9½ 12 6	318 341	1192 1290	953	360	672 646
14	Erebus	105 0	28 10	14 1	328	715	372	30	
15	Euphrates	215 7	40 6	16 7½	570	2402		620	
16	Fairy (iron)	144 8	21 1½	4 10 5 10	71·5 82	168 196	312	128	364 321
17	Greenock (iron)	213 0	37 4½	15 0	450	1980	1418	338	
18	Highflyer	192 0	36 4	15 9	465	1737	1153	250	
19	Hogue	184 0	48 4½	22 10	820	3155	1846	450	
20	Horatio	154 3	40 2½	19 1½	537	1707	1090	250	
21	Megæra (iron)	207 0	37 10	16 0	487	2048	1395	350	780
22	Minx (iron)	131 0	22 1	5 2½	82	203	303	100	234
23	Ditto, horse-power diminished	,,	,,	,,	,,	,,	,,	100	32
24	Miranda	196 0	34 0	13 6	374	1522	1039	250	
25	Niger	194 4	34 1	14 10 14 6½	403 392	1362 1323	1072	400	828 919
26	Phœnix	174 7	31 10	13 9½ 13 1½	247 327	1225 1140	809	260	382 489
27	Plumper	140 0	27 6	10 11 12 3	204 241	539 652	490	60	148 149
28	Rattler	179 6	32 8½	11 3 13 6	274 330	870 1078	888	200	428 436
29	Reynard	147 8	27 10	9 6 10 11	184 222	478 604	516	60	165 153
30	Rifleman	150 0	26 7	9 3 9 3	173 173	484 484	486	200	348 366
31	Ditto, horse-power diminished	,,	,,	9 3½ 10 2½	175 199	487 565	,,	100	188 190
32	Sanspareil	200 6	52 1	22 9	920	3484	2334	350	408
33	Sharpshooter (iron)	150 0	26 7½	9 1½ 9 3	192 196	505 518	489	200	365 175
34	Simoom (iron)	246 0	41 0	17 0	567	2789	1980	350	
35	Teazer (iron)	130 0	21 9½	5 3	2·9	205	296	100	
36	Ditto, horse-power diminished	,,	,,	,, ,,	,,	,,	,,	40	128
37	Termagant	210 1	40 6	17 1	587	2403	1547	620	1351
38	Vulcan (iron)	220 0	41 5	15 6	465	2076	1764	350	793
39	Wasp	180 0	33 10	14 9	395	1337	970	100	

N.B.—The Experiments made on each Vessel are continued, and cor-

IN HER MAJESTY'S NAVY.

of the Admiralty in the year 1852.)

Vessel.

	Speed per hour.	When completed and tried.	Constructor of Vessel.	Remarks, and state of the Vessel at her trial trip.
	Knots.	Year.		
1	7·147	1848	Old 74 . .	Not rigged, but ballasted.
2	6·75	1847	Old Frigate .	Rigged and fully equipped for sea.
3	7·818	1849	Deptford Dockyard	Not rigged, but ballasted.
4	8·395	1849	Fincham . .	Rigged and fully equipped.
5	6·822 7·501 screw & paddles	1842	Symonds . .	Fitted also with paddles, speed 7·501 knots.
6	5·816	1849	Old 74 . .	Rigged and partially equipped.
7	....	1851	Woolwich Dockyard	Not completed.
8	9·289	1848	. . .	Rigged and partially equipped.
9	7·366	1848	Fincham . .	Jury rigged, ballasted to trim.
10	10·293	1850	,, . .	Altered at stern, rigged and fully equipped.
11	10·75	1852	Pembroke Dockyard	Not completed.
12	10·537	1843	Rennie . .	Not rigged.
13	10·254 9·375	1848	Fincham . .	Not rigged, but ballasted to trim.
14	esti-mated at 3·5	1845	Old 28 . .	Rigged and fully equipped.
15	....	1851	Deptford Dockyard	Not completed.
16	13·324 11·891	1845	Ditchburn .	Not rigged, light. Rigged and fully equipped.
17	....	not complete	Scott and Sinclair	Not completed.
18	....	,,	Woolwich Dockyard	Not completed.
19	by log 7·5	1848	Old 74 . .	Rigged and fully equipped.
20	8·5	1851	,, . .	Not completed.
21	9·75	1850	Fairbairn . .	Not rigged, but ballasted to trim.
22	9·137	1848	Symonds . .	Ditto.
23	4·515	1849	,, . .	Ditto.
24	....	not complete	Sheerness Dockyard	Not completed.
25	9·494 10·427	1849	Lang . .	Rigged and fully equipped.
26	7·106 8·74	1848 1849	Seppings . .	Not rigged, but ballasted. Rigged.
27	7·418 6·497	1848	Fincham . .	Rigged and partially equipped. Rigged and fully equipped for sea.
28	10·074 9·639	1844 1845	Symonds . .	Not rigged, but ballasted. Rigged and fully equipped for sea.
29	8·238 7·3	1848 1849	Symonds . .	Not rigged, light. Rigged and fully equipped.
30	3·096 9·499	1847	Fincham . .	Before stern made finer, & rigg. & ball. Subsequently to ditto ditto.
31	8·011 7·977	1848	,, . .	Horse-power diminished.
32	8·0	not com.	. . .	Not completed.
33	9·782 9·189	1847	Fincham, same lines as Rifleman .	Not rigged, but ballasted. Rigged and partially equipped.
34				
35	....	1851	Robert Napier .	Not completed. Troop ship.
36	6·315 7·685	1847 1848	Symonds . .	Not rigged. Before stern made finer. Ditto. Subsequently to do.
37	9·51	1849	White, of Cowes	Rigged and equipped for sea.
38	9·605	1849	Ditchburn .	Not rigged, but ballasted.
39	....	1851	Deptford Dockyard	Not completed.

TABLE OF SCREW STEAMERS

2.—*Propeller, and*

	Name of the Vessel.	Tonnage—Builders' old Measurement.	Horses' Power, Nominal	Diameter of Screw.	Pitch of Screw	Length of Screw.	Revolutions. Intended	Revolutions. Actual at Trial.
		Tons.	H. P.	ft. in.	ft. in.	ft. in.	No.	No.
1	Ajax	1761	450	16 0	17 11	3 2	45	48
2	Amphion	1474	300	15 0	21 0	2 6	48	45
3	Archer	970	200	9 0	7 9	1 4	144	108·4
4	Arrogant	1872	360	15 6	15 0	2 6	60	55·5
5	Bee	43	10	3 1	3 9			240
6	Blenheim	1832	450	16 0	20 0	3 4	45	43
7	Briak	1074	250				90	
8	Conflict	1038	400	13 6	16 6	2 9	75	68
9	Dauntless	1497	580	14 8	18 0	3 0	70	55·3
10	Do., lengthened and stern altered	1569	,,	,,	,,	,,	,,	68·28
11	Desperate	1037	400	13 0	14 0	2 4	87·28	
12	Dwarf	164	90	5 8	8 0	1 0	180	182·8
13	Encounter	953	360	12 0	15 0	2 6	80	{78 / 72
14	Erebus	872	30				70	
15	Euphrates		620					
16	Fairy	312	128	{5 4 / 6 2}	8 0 / 8 0	1 0 / 1 4		{258 / 220
17	Greenock	1418	338	14 0	13 0	2 2	98	
18	Highflyer	1153	350				85	
19	Hogue	1846	450	16 0	20 0	3 4	45	50
20	Horatio	1090	250				55	
21	Megæra	1395	350				55	
22	Minx	303	100	4 6	5 0	1 0	220	254
23	Do., H. P. diminished	,,	10	5 0	3 8			140
24	Miranda	1039	250				77·72	
25	Niger	1072	400	12 6	17 0	2 10	75	{68·8 / 74·32
26	Phœnix	809	260	{12 0 / 11 10½}	12 8 / 9 8	2 1 / 1 7}	92	{68 / 96
27	Plumper	490	60	9 0	5 7	1 0	155	{115 / 112
28	Rattler	888	200	10 0	11 0	1 3	100	{104 / 107·92
29	Reynard	516	60	{8 9 / 8 11}	8 0 / 7 3	1 4 / 1 4}	120	{108·86 / 112
30	Rifleman	486	200	8 0	9 0	1 6	144	{119·25 / 129
31	Do., H. P. diminished	,,	100	{8 0 / 9 0}	9 0 / 9 0	1 6 / 1 6}	144	{110 / 98·75
32	Sanspareil	2334	350				55	
33	Sharpshooter	489	200	{8 0 / 9 0}	9 0 / 9 0	1 6 / 1 6}	144	{140·7 / 124·5
34	Simoom	1980	350				55	
35	Teaser	296	100	4 6	5 10	1 0	220	300
36	Do., H. P. diminished	,,	40	5 0	7 0	1 2		192·09
37	Termagant	1547	620	{15 6 / 15 6}	18 0 / 17 2½	3 0 / 2 10}	70	{66 / 72
38	Vulcan	1764	350	14 0	16 6	2 9	65	66·5
39	Wasp	970	...				121	

N.B.—The Experiments made on each Vessel are continued and cor-

IN HER MAJESTY'S NAVY—*continued.*

Proportional Numbers.

	Rate of Screw.	Rate of Ship.	Slip of the Screw.		Ratio of				
					Vessel's length to breadth	Screw's Pitch to Diameter	Immersed ⊕ Section to Screw's disc.	Nominal H.-Power to ⊕ Section.	Indicated H.-Power to ⊕ Section.
	Knots.	Knots.	Knots.	p. Cent.					
1	8·482	7·147	1·335	15·74	3·625	1·12	4·01	0·56	1·05
2	·321	6·75	2·571	27·58	4·1	1·4	3·09	0·55	1·08
3	8·293	7·818	0·475	5·73	5·32	0·86	5·84	0·54	0·93
4	8·11	8·295	negative 0·884	negative 1·02	4·37	0·96	3·07	0·62	1·07
5	8·877	6·822	2·055	23·15	5·17	1·21	3·76	0·35	
6	8·483	5·816	2·667	31·4	3·73	1·25	3·67	0·61	1·27
7					5.53				
8	41·067	9·289	1·778	16·06	5·6	1·22	2·81	0·99	1·93
9	9·818	7·366	2·452	24·97	5·28	1·22	3·09	1·11	1·55
10	12·123	10·293	1·83	15·09	5·48	,,	,,	,,	2·33
11					5·6	1·08			
12	14·427	10·537	3·89	26·96	7·87	1·41	1·74	2·04	4·91
13	11·541 10·653	10·254 9·375	1·287 1·278	11·15 11·99	5·73	1·25	2·81 3·01	1·13 1·06	2·11 1·89
14					3·64				
15					5·32				
16	20·359 17·36	13·324 11·891	7·035 5·469	34·55 31·5	6·84	1·5 1·29	3·2 2·74	1·79 1·56	5·08 3·91
17					5·69				
18					5·28				
19	9·864	by log. 7·5	2·364	23·96	3·8	1·25	4·08	0·55	
20					3·83				
21					5·47				
22	12·533	9·137	3·396	27·09	5·93	1·11	5·15	1·22	2·86
23	5·062	4·515	0·547	10·8	,,	0·73	4·17	0·12	0·38
24					·76				
25	11·537 12·462	9·494 10·427	2·043 2·035	17·7 16·33	5·6	1·36	3·28 3·19	0·99 1·02	2·05 2·34
26	8·496 9·153	7·106 8·74	1·39 0·413	16·36 4·51	5·48	1·05 0·81	3·16 2·97	0·75 0·79	1·1 1·49
27	6·333 6·168	7·418 6·497	negative 1·058 0·329	negative 17·13 5·33	5·09	0·62	3·2 3·78	0·29 0·25	0·72 0·62
28	112 11·709	10·074 9·639	1·21 2·07	10·72 17·67	5·39	1·1	3·49 4·2	0·73 0·6	1·56 1·32
29	8·59 8·009	8·258 7·3	0·352 0·709	4·09 8·85	5·3	0·91 0·81	3·06 3·55	0·32 0·27	0·89 0·69
30	10·586 11·452	8·096 9·499	1·49 1·953	23·52 17·05	5·64	1·12	3·44	1·15	2·01 2·12
31	9·765 8·766	8·011 7·977	1·754 0·789	17·06 9·0	5·64	1·12 1·0	3·48 3·12	0·57 0·5	1·07 0·95
32					3·84				
33	12·49 11·052	9·782 9·189	2·708 1·863	21·68 16·85	5·63	1·12 1·0	3·81 3·08	1·04 1·02	2·12 1·86
34					6·0				
35	11·50	6·315	5·192	45·12	5·96	1·29	5·21	1·2	2·11
36	13·263	7·685	5·578	42·05	5·96	1·4	4·23	0·48	1·54
37	11·718 12·391	9·16 9·51	2·552 2·881	21·77 23·25	5·19	1·16 1·11	2·74 3·11	1·2 1·05	2·4 2·3
38	10·823	9·605	1·218	11·25	5·31	1·18	3·02	0·75	1·7
39					5·32				

respond throughout the three Tables of Screw Steamers in H. M. Navy.

TABLE OF SCREW STEAMERS

3.—*Engines and*

	Name of the Vessel.	Manufacturers of the Machinery.	Description of Engines.	Diameter of Cylinders.	Length of Stroke.	Revolutions per min. Intended.	Revolutions per min. Actual at Trial.	Indicator pressure on piston per sq. in.	Load on the Safety Valve.	Height of Engine Barometer.	Horses' Power. Nominal.	Horses' Power. Indicated.	Multiple of Gearing, when used.
			Cyls.	inches.	f. i.	No.	No.	lb.	lb.	In.	H. P.	H. P.	
1	Ajax	Maudslay & Field	Horizontal 4	55	2 6	45	48	12·24	6	24½	450	846	Direct.
2	Amphion	Miller & Ravenhill	Ditto . . 2	48	4 0	48	45	15	10	25	300	592	„
3	Archer	Ditto	Ditto . . 2	46	3 0	48	36·16	15·8	10	26	200	345	3 to 1
4	Arrogant	Penn & Son	Horizont. Trunk 2	60—34 = 55	3 0	60	55·5	13	5	27	360	623	Direct
5	Bee . .	Maudslay & Field	Beam . . 1	20	2 0	..	48	..	..	27½	10	..	5 to 1
6	Blenheim	Seaward & Capel	Horizontal 4	52	3 0	45	43	14·13	10	27	450	938	Direct.
7	Briak	Scott, Sinclair, & Co.	Ditto . . 2	52	3 6	40	..	..	..	..	250	..	2·25 to 1
8	Conflict	Seaward & Capel	Ditto . . 4	46	2 0	75	68	14·19	16	25	400	777	Direct.
9	Dauntless	Rob. Napier	Ditto . . 2	84	4 0	36	24·8	12·42	8	25½	580	811	2·276 to 1
10	Do. lengthened & stern altered	Ditto	Ditto . . 2	„	„	„	30	15·11	„	26½	„	1218	„
11	Desperate	Maudslay & Field	Ditto . . 4	55	2 6	40	..	..	..	..	400	..	2·182 to 1
12	Dwarf	Rennies	Vertical . 2	40	2 8	35	35·5	15	8	27	90	216	5·15 to 1
13	Encounter	Penn & Son	Horizont. Trunk 2	60—34 = 55	3 3	30	78	13·31	..	26	360	672	Direct.
14	Erebus	Maudslay & Field	Locom. H. Pres. 2	..	..	..	..	..	..	..	30	..	„
15	Euphrates	Seaward & Capel	Horizontal 4	62	3 6	35	..	..	..	..	620	..	2 to 1
16	Fairy	Penn & Son	Vert. Oscil. 2	42	3 0	36·5	51·6	14	..	..	128	364	5 to 1
17	Greenock	Scott, Sinclair, & Co.	Horizontal 2	71	4 0	42	..	..	..	..	338	..	2·33 to 1
18	Highflyer	Maudslay & Field	Ditto . . 2	55	4 0	31·5	..	..	..	..	250	..	2·7 to 1
19	Hogue	Seaward & Capel	Ditto . . 4	51½	3 0	45	50	..	..	26½	450	..	Direct.
20	Horatio	Ditto	Ditto . . 2	54	3 0	45	..	..	..	..	250	..	2 to 1
21	Megæra	G. & J. Rennie	Ditto . . 4	49½	2 0	55	..	..	..	..	350	..	Direct.
22	Minx	Miller & Ravenhill	Vert. Oscil. 2	34	2 9	55	53·5	12·19	10	26	100	234	4 to 1
23	Ditto, H.-P. diminished	Seaward & Capel	H. Pres. Horizont. 2	..	..	..	140	39	60	..	10	32	Direct.
24	Miranda	Rob. Napier	Horizontal 2	56	3 9	32	..	..	..	..	250	..	2·43 to 1
25	Niger	Maudslay & Field	Ditto . . 4	47⅛	1 10	75	74·3	15·63	8	24½	400	919	Direct.
26	Phœnix	Penn & Son	Vert. Oscil. 2	62	4 6	23	24	12·37	6	26½	260	489	4 to 1
27	Plumper	Miller & Ravenhill	Ditto . . 2	27	2 0	62	46	23·2	14	26½	60	148	2·5 to 1
28	Rattler	Maudslay & Field	Vertical . 4	40½	4 0	25	26	13·42	5	..	200	428	4 to 1
29	Reynard	G. & J. Rennie	Horizontal 2	28	2 0	60	54·4	20·27	14	..	60	165	2 to 1
30	Rifleman	Miller & Ravenhill	Ditto . . 2	46	3 0	48	43	14·12	10	25½	200	366	3 to 1
31	Ditto, H.-P. diminished	Ditto	Vert. Oscil. 2	34	2 9	48	44	14·12	10	26½	100	188	2·5 to 1
32	Sans-pareil	Boulton & Watt	Horizont. Oscil. 4	44	2 6	55	..	..	..	..	350	..	Direct
33	Sharpshooter	Miller & Ravenhill	Horizontal 2	46	3 0	48	46·9	14·4	10	26	200	466	3 to 1
34	Simoom	Boulton & Watt	Horizont. Oscil. 4	44	2 6	55	..	..	..	..	350	..	Direct.
35	Teaser	Miller & Ravenhill	Vert. Oscil. 2	34	2 9	55	50	11·6	10	..	100	175	4 to 1
36	Ditto, H.-P. diminished	Penn & Son	Ditto . . 2	27	2 6	..	51·5	14·35	9	26½	40	128	3·73 to 1
37	Termagant	Seaward & Capel	Horizontal 4	62	3 6	35	36·5	14·45	14	27	620	1351	2 to 1
38	Vulcan	G. & J. Rennie	Ditto . . 4	49½	2 0	55	66·5	12·78	8	27	350	793	Direct.
39	Wasp	Miller & Ravenhill	Vert. Oscil. 2	34	2 9	60	..	..	..	..	100	..	..

IN HER MAJESTY'S NAVY—*continued.*

Proportional Numbers.

	Name of Vessel.	Ratio of Nominal Power to		Ratio of Indicated Power to		Numbers showing the relative performance of the vessels, assuming the speed to vary directly as the cube root of the power, and inversely as the				Draught of Water for Dispt.
		Midship Section.	(Dispt.) $\frac{2}{3}$	Midship Section.	(Dispt.) $\frac{2}{3}$	Area of Midship Section.		(Displacement) $\frac{2}{3}$		
						(Speed) 3 × ⊕ sect. Nominal Power.	(Speed) 3 × ⊕ sect. Indicated Power.	(Speed)3 × (Dispt.) $\frac{2}{3}$ Nominal Power.	(Speed)3 × (Dispt.) $\frac{2}{3}$ Indicated Power.	
										ft. in.
1	Ajax	0·56	2·12	1·05	3·98	645·7	348·2	172·1	91·5	22 6½
2	Amphion	0·55	1·87	1·08	3·69	559·7	283·5	164·0	83·1	19 0
3	Archer	0·54	1·73	0·93	2·99	888·8	515·3	276·4	159·7	14 1
4	Arrogant	0·62	1·98	1·07	3·43	919·5	531·1	287·6	166·1	18 10½
5	Bee	0·35	0·97	....	....	895·3	....	327·9	....	3 5½
6	Blenheim	0·61	2·27	1·27	4·73	322·6	154·7	86·6	41·5	21 1½
7	Brisk	....	....	....	....	....	....	....	....	....
8	Conflict	0·99	3·13	1·93	6·08	805·5	414·5	225·8	131·6	14 6
9	Dauntless	1·11	3·38	1·55	4·73	359·9	257·4	117·9	84·4	16 4
10	Do. length-end & stern altered	....	3·37	2·33	7·09	982·0	467·6	322·9	153·8	16 4
11	Desperate	....	....	....	....	....	....	....	....	....
12	Dwarf	2·04	4·23	4·91	10·16	571·9	238·3	276·3	115·1	5 6
13	Encounter	1·13 1·06	3·2 3·03	2·11 1·89	5·98 5·45	952·3 780·4	509·6 434·8	326·6 271·3	180·1 151·1	11 9½ 12 6
14	Erebus	....	....	....	....	....	....	....	....	....
15	Euphrates	....	....	....	....	....	....	....	....	....
16	Fairy	1·79 1·56	4·2 3·79	5·08 3·91	11·94 9·52	1322·0 1077·2	464·8 428·9	569·6 443·2	197·9 176·5	4 10 5 10
17	Greenock	....	....	....	....	....	....	....	....	....
18	Highflyer	....	....	....	....	....	....	....	....	....
19	Hogue	0·55	2·09	....	....	768·7	....	201·7	....	22 10
20	Horatio	....	....	....	....	....	....	....	....	....
21	Megæra	....	....	....	....	....	....	....	....	....
22	Minx	1·22	2·89	2·86	6·79	625·5	266·7	263·5	112·3	5 2½
23	Do., H. P. diminished	0·12	0·29	0·38	0·91	754·7	238·8	317·9	100·6	5 2½
24	Miranda	....	....	....	....	....	....	....	....	....
25	Niger	0·99 1·02	3·25 3·32	2·05 2·34	6·74 7·63	862·2 1111·0	416·6 483·2	262·9 341·5	127·0 148·5	14 10 14 6½
26	Phœnix	0·75	2·27	1·1	3·34	478·9	325·6	158·0	107·4	13 9½
27	Plumper	0·25	0·79	0·62	1·99	1101·5	442·1	343·7	137·9	12 3
28	Rattler	0·73 0·6	2·19 1·9	1·56 1·32	4·69 4·15	1400·6 1477·7	654·5 676·7	465·8 470·8	217·7 215·6	11 3 13 6
29	Reynard	0·27	0·84	0·69	2·15	1439·3	562·2	463·3	181·0	10 11
30	Rifleman	1·15	3·24	2·01 2·19	5·65 5·95	459·0 741·4	263·6 404·1	163·6 264·2	93·9 144·0	9 3 9 3
31	Do., H. P. diminished	0·57 0·5	1·61 1·46	1·07 0·95	3·04 2·78	899·7 1010·1	478·6 531·9	318·2 346·9	169·3 182·6	9 3½ 10 2½
32	Sansparsil	....	....	....	....	....	....	....	....	....
33	Sharpshooter	1·04 1·02	3·15 3·1	2·12 1·86	6·43 5·66	898·6 760·4	440·4 416·4	296·8 250·2	145·4 137·0	9 1½ 9 3
34	Simoom	....	....	....	....	....	....	....	....	....
35	Teaser	1·20	2·88	2·11	5·05	208·8	118·9	87·6	49·9	5 3
36	Do., H. P. diminished	0·48	1·15	1·54	3·68	940·6	293·4	394·5	123·1	5 3
37	Termagant	1·2 1·06	3·84 3·47	2·4 1·25	7·72 4·11	642.2 258·8	319.7 218·6	200·4 79·1	99·8 66·8	15 3 17 0
38	Vulcan	0·75	2·15	1·7	4·87	1177·2	519·6	412·0	181·8	15 6
39	Wasp	....	....	....	....	....	....	....	....	....

N.B.—The Experiments made on each Vessel are continued and correspond throughout the three Tables of Screw Steamers in H. M. Navy.

PARTICULARS OF THE *GREAT EASTERN* STEAM-SHIP.

(*Communicated by J. Scott Russell, Esq.*)

Material. *Of Iron.*	
Builders. *J. Scott Russell and Co.*	
Gross Tonnage	22,500 Tons.
Nominal Horse-power, total	2600 H. P.
Length between Perpendiculars	680 feet.
Length on Deck	691 „
Breadth, extreme	83 „
Depth of Side	58 „
Estimated Draught, light	20 „
Ditto, laden	30 „
SCREW ENGINES. *James Watt and Co., Makers.*	
Nominal Horse-power of Screw Engines	1600 H. P.
Description. *Horizontal Direct-acting.*	
Geared or Ungeared? *Ungeared.*	
Number of Cylinders. *Four.*	
Diameter of each Cylinder	84 inches.
Length of Stroke	4 feet.
No. of Strokes of Engine per minute	55
Kind of Boilers. *Tubular.*	
Pressure of Steam	25 lbs.
Kind of Screw Propeller. *Four Blades, ordinary.*	
Diameter of Screw	24 feet
Pitch of Screw	44 „
PADDLE-WHEEL ENGINES. *J. Scott Russell and Co., Makers.*	
Nominal Horse-power of Paddle-wheel Engines	1000 H. P.
Description. *Oscillating.*	
Number of Cylinders. *Four.*	
Diameter of each Cylinder	74 inches.
Length of Stroke	14 feet.
Kind of Boilers. *Tubular.*	
Pressure of Steam	25 lbs.
Kind of Paddle Wheels. *Common.*	
Diameter of Paddle Wheels	56 feet.
Length of floats of ditto	13 „
Depth of floats of ditto	3 „
Any provision for reefing? *Yes, to reef.*	
Total Coals carried	10,000 tons.

.	.	.	Wood	I	507	400	225	0	27	La
.	.	.	Wood	1	503	400	228	0	29	Di
.	.	.	Iron		168	150	158	0	20	Tu

and he

TABLE OF PROPORTIONS OF MARINE ENGINES AND BOILERS, compiled by the Engineering Department of H.M. Dockyard, Woolwi delivered by the various manufacturing Engineers, for a pair of Engines, with Paddle Wheels and Tubular Boilers; the Weight of Mach limited to 300 tons, and the Coals carried in Engine Room not to be less than 300 tons: Power left unlimited, except by Weight and La

Numbers for Manufacturers.	Description of the proposed Engines.	Horses' Power, Admiralty estimate.	Horses' Power, Contractors' estimate.	Estimated weight of Engines.	Estimated weight of Boilers and their Apparatus.	Estimated weight of Water in Boilers.	Estimated weight of Coal-boxes.	Estimated weight of Paddle Wheels.	Estimated Weight of Duplicates and spare Gear.	Estimated total weight.	Diameter of Cylinders.	Length of Stroke.	No. of Strokes per minute.	Diameter of Paddle Wheels.	Breadth of Paddles.	Diameter of necks of Paddle shaft.	Weight of Coals in Boxes.	Number of days' consumption.	Estimated consumption per horse per hour.	Cost of Engines, Boilers, and Coal-boxes.	Cost of Paddle Wheels.	Cost of Duplicates and spare Gear.	Total cost, with iron tubes.	Cost per Horse-Power, Admiralty estimate.	Extra Cost for brass tubes	Cost per Horse-Power Contractors' estimate	Cost per Horse exclusive of spare Admiralty estimate	Weight of total Machinery, per Actual Horse-Power.
No.		H.P.	H.P.	Tns.	Tns.	Tns.	Tns.	Tns.	Tns.	Tns.	inches.	ft. in.	No.	ft. in.	ft. in.	in.	Tns.	Dys.	lbs.	£	£	£	£ s.	£ s.	£ s.	£ s.	£ s.	cwt.
1	Oscillating	544	544	105	78	48	16	26	27	300	85	6 6	17½	25 0	10 6	16½	250	9	5	22,400	1460	2240	26,100	48 0	420	48 0	43 17	11·03
2	Direct . .	515	510	127	73	35	17	33	15	300	84	5 9	19	24 6	9 0	18	345	9¼	6¼	19,820	1400	480	21,700	42 3	800	42 11	41 4	11·65
3	,,	508	500	125	65	52	20	30	8	300	84	5 6	20	26 6	9 4	15	300	9	6	23,000	580	450	24,030	47 6		48 1	46 8	11·81
4	Oscillating	501	500	117	70	28	16	38	23	292	82½	6 0	18½	27 0	9 0	16	340	9 7/8	7	20,350	1650	1450	23,450	46 16	500	46 18	43 18	11·65
5	Direct . .	501	500	123	68	46	15	35	13	300	83	5 8	19½	26 6	9 0	16½	344	9	7	23,000		1070	24,070	48 1		48 3	45 18	11·97
6	Oscillating	500	500	99	78	53	18	40	12	300	81	6 9	17	27 0	9 6	16	301	8⅝	6¼	16,260	1740	720	18,720	37 9	680	37 9	36 0	12·00
7	Direct . .	496	500	150	50	50	20	20	10	300	83	5 6	variable	25 6	9 6	17	340	13	4¼ to 6	16,000		1000	17,000	34 5		34 0	32 0	12·09
8	,,	484	480	140	71	31	11	30	17	300	82	5 6	20	26 0	9 0	14	400	15	..	21,550		1250	22,800	47 2	500	47 0	44 10	12·39
9	,,	469	470	130	62	27	17	44	20	300	81	5 4½	21	26 6	9 6	15	325	12	5½	18,827	1645	1528	22,000	46 18	560	47 16	43 13	12·79
10	,,	463	460	148	48	40	15	29	20	300	80⅞	5 3	20	26 0	8 3	14½	300	10½	6	17,250	750	1400	19,400	41 18		42 3	38 18	12·96
11	Oscillating	460	460	110	69	46	23	26	26	300	76½	7 6	16	29 6	9 6	17½	360	12½	6	19,640	850	1450	21,940	47 14	210	47 14	44 11	13·04
12	Double Cyl	456	450	148	72	41	8	26	5	300	4·55⅛ = 2·78⅛	6 0	18½	26 9	10 0	14½	320	10	7	18,900		810	21,390	46 18	470	47 11	45 3	13·16
13	Direct . .	444	444	105	70	50	19	37	19	300	78	5 9	19	26 0	9 0	15½	360	11⅝	6½	16,080	1680	1490	19,250	43 7	590	43 7	40 0	13·51
14	,,	427	426	140	60	38	16	24	20	298	77	5 6	20	25 6	9 0	14½	304	11 3/16	6	17,700	680	1060	19,440	45 11	530	45 13	43 1	13·96
15	,,	423	420	135	51	58	10	23	20	297	77	5 4	20	26 0	8 6	14	349	12½	6	13,980	1160	1340	16,480	38 19	730	39 5	35 16	14·04
16	,,	343	342	125	50	40	13	18	13	259	70	5 0	18	25 0	8 0	14	380	15	7	11,450	800	1000	13,250	38 13	550	38 15	35 14	15·10
17	Beam . .	313	312	140	50	40	13	18	15	276	65	6 0	18	25 0	8 0	13	340	14½	7	11,450	800	1000	13,250	42 7	550	42 9	39 3	17·63
18	Oscillating	313	312	125	50	40	13	18	13	259	65	6 0	18	25 0	8 0	13	345	14½	7	11,450	800	1000	13,250	42 7	550	42 9	39 3	16·55

Quito	Iron	1	...	400	248	0	30	0	Di Tu
Ripon	Iron	1	1308	450	231	$\frac{8}{10}$	33	$\frac{9}{10}$ $\frac{3}{4}$	La
Sea Serpent . . .	Iron	1	...	90	157	0	16	6	Tu
South-Western . .	Iron		131	90	143	0	18	0	Di
Solent	Wood	1	1270	400	277	4	34	11	Di
Tamar	Wood	1	1501	400	287	6	33	8	Di
Tyne	Iron	1	1788	400	296	7	36	2	Di
Valetta	Wood	1	507	400	225	0	27	1	La
Vectis	Wood	1	503	400	228	0	29	1	Di
Wonder	Iron		168	150	158	0	20	4	Tu

and he

Numbers for Manufacturers.	Description of the proposed Engines.	Nominal Horse-Power.	Indicated Horse-Power.	Diameter of Paddle Shaft at Journals.	
No.				in.	
1	Oscillating	850	...	23½	Tu
2	Direct . .	873	2828	22½	
3	,,	873	2828	22½	
4	Oscillating	768	...	20	Fl
5	Direct . .	768	2104	20	
6	Oscillating	768	2104	20	
7	Direct . .	428	...	16	Tu
8	,,	396	...	15	
9	,,	394	...	15	
10	,,	394	...	15	
11	Oscillating	394	...	15	
12	Double Cy.	376	...	14½	
13	Direct . .	304	...	12½	
14	,,				
15	,,				
16	,,				
17	Beam . .				
18	Oscillating				

Table of Proportions of Marine Engines and Boilers—*continued.*

No.	Numbers for Manufacturers.	Horses' Power, Admiralty estimate.	Time for making.	Time for fixing.	Place where fitted on board.	Length of the Engine-Room. ft.	Length of the Engine-Room. in.	Net Length of the Engine. ft.	Net Length of the Engine. in.	Length of the Connecting Rod. ft.	Length of the Connecting Rod. in.	Ratio of Connecting Rod to Crank.	Dip of Wheel, measured from assumed water line. ft.	Dip of Wheel, measured from assumed water line. in.	Height of centre of Wheel above that line. ft.	Height of centre of Wheel above that line. in.	Ratio of Diameter of Wheel to Crank.	Velocity of extremity of Paddle Floats, by the Manufacturers. feet per m.	Ditto, calculated by the Admiralty velocities. feet p' m.	Boiler's Length. ft.	Boiler's Length. in.	Boiler's extreme Breadth. ft.	Boiler's extreme Breadth. in.	Boiler's Height, without Steam Chest. ft.	Boiler's Height, without Steam Chest. in.	Boiler's Height, with Steam Chest. ft.	Boiler's Height, with Steam Chest. in.	Ratio of the circumscribing parallelopiped to the Horse Power.	Boiler's Breadth of Fires. ft.	Boiler's Breadth of Fires. in.	Boiler's Area of the Fire-surface. sq. ft.	Ratio, per Admiralty Horse Power.	Boilers, length of the Tubes. ft.	Boilers, length of the Tubes. in.	External Diameter. in.	Number of Tubes. No.	Total Area through the Tubes. sq.ft.	Total Area of effective Heating Surface. sq.ft.	Ratio, per Admiralty Horse Power.	Number of Fires. No.
1	544	9	3	E. I. Docks	53	0	17	6	13	8	4·20	3	9	8	9½	7·72	1379	1370	23	3	24	7	12	3½	16	7	10·81	2	9½	240·0	·441	7	0	3½	..	..	5500	10·1	12
2	515	6	3	London or Liverpool.	48	3	17	1	7	7	2·76	3	6	8	9	9·04	1462	1469	18	7	23	1½	14	2	18	1	11·82	2	3½	284·1	·552	6	4	3	1232	7833	8349	16·2	16
3	508	6	1½	Glasgow .	56	2	17	7	7	10	2·94	..	..	..	..	9·94	1665	1670	19	9	27	2	11	7⅛	16	8	12·28	2	6	323·3	·502	6	2	3	768	5429	6019	11·8	16
4	501	8	3	E. I. Docks.	56	1	13	5	13	2	4·39	..	..	..	..	9·01	1571	1571	18	11	19	0	10	4	14	6	7 41	1	10½	262·5	·524	6	6	3	1042	6869	6776	13·5	16
5	501	8	2	,, .	46	9	11	10	..	..	..	4	3⅜	8	11½	9·35	1602	1601	19	11	24	0	10	11	15	4	10·41	2	4	264·4	·528	6	0	3½	984	3688	6421	12·8	16
6	500	6	2	Liverpool .	52	3	17	1	12	7	3·77	4	9½	8	9	8·12	1446	1452	22	1	21	8½	11	7	16	7	11·06	2	7	..	..	6	11	3½	924	7087	5437	10·9	12
7	496	10	2½	Greenock .	56	0	11	11	8	9	3·28	..	..	8	9	9·56	variable	1607	21	1	23	2	11	11½	17	6	11·77	2	8	240·0	·484	6	6	3½	1056	7964	7210	14·5	12
8	484	8	2½	Blackwall .	56	3	13	3½	8	3	3·0	4	2½	8	10½	9·48	1641	1609	18	7	19	1	9	7	14	6	7·02	2	6	..	..	6	6	3	..	..	..	..	12
9	469	5½	2	Limehouse .	49	1	19	1½	..		..	4	6	8	9½	9·86	1748	1665	15	6	23	5	11	0	no steam chest		8·51	..		287·0	·612	..	..	..	..	..	..	..	
10	463	7	2	E. I. Docks	45	10	15	6	6	0½	2·3	4	2½	8	10	9·98	1647	1670	16	3½	25	1	12	8	15	7	11·18	2	10	267·75	·578	5	7	3	1008	7125	6479	14·0	14
11	460	6	2½	Liverpool .	56	3	18	3	13	9	3·67	6	0½	8	9	7·89	1487	1462	21	1	23	9	11	6½	16	1	12·56	2	3	288·0	·626	6	0	3½	1134	7632	6483	14·1	16
12	456	5	2	E. I. Docks	56	2	18	1	12	5½	5·07	4	5	8	10	10·76	1538	1766	18	11	24	0	11	8	16	2	11·61	2	6	..	..	5	0	3½	1900	8595	6218	13·6	12
13	444	6	2	Liverpool .	56	2	14	1½	13	10	4·88	4	2½	8	10	9·20	1557	1576	22	1	19	5	11	6½	16	1	11·14	2	3½	..	..	6	11	3½	792	6570	6218	14·0	12
14	427	10	2½	,,	47	8	16	7	14	0	5·09	4	0	8	9	9·27	1522	1562	20	2	22	1	12	1	18	2	12·60	2	3½	191·16	·448	6	10	3	925	6531	6499	15·2	12
15	423	9	2	London . .	48	1	12	3	7	6½	2·83	4	0	8	9	9·59	1602	1607	20	0	18	6	12	3	15	6	10·71	3	5	210·0	·498	5	9	3	980	6927	5868	13·9	8
16	343	7	1½	Greenock .	42	1	9	5	8	9½	3·52	3	7⅜	8	11	10·03	1418	1655	17	10	19	0	12	10	17	5	12·70	2	6	195·0	·568	6	0	3½	880	6931	5655	16·5	12
17	313	7	1½	,,	52	4	21	0	13	5	4·47	3	7⅜	8	11	8·36	1418	1458	17	10	19	0	12	10	17	5	13·80	2	6	195·0	·623	6	0	3½	880	6931	5655	18·1	12
18	313	7	1½	,,	47	9	15	11	12	7½	4·33	3	7⅜	8	11	8·6	1418	1486	17	8	19	0	12	10	17	5	1375	2	6	195·0	·623	6	0	3½	880	6931	5655	18·1	12

TABLE No. IX.

STATISTICAL RETURN by the REGISTRAR-GENERAL of the BOARD OF TRADE, showing the progressive advancement of Steam Navigation in the British Empire.

Year.	Merchant Steamers built and registered in each year in the				No. of Merchant Steamers belonging to the British Empire.	
	United Kingdom.		Plantations and Channel Islands.			
	Vessels.	Tons.	Vessels.	Tons.	Vessels.	Tons.
1814	5	285	1	387	2	456
1815	9	786	1	608	10	1,633
1816	8	568	1	670	15	2,612
1817	7	421	3	1633	19	3,950
1818	6	1,340	3	1198	27	6,441
1819	4	342	...	...	32	6,657
1820	8	655	1	116	43	7,243
1821	22	3,008	1	258	69	10,534
1822	27	2,449	1	185	96	13,125
1823	19	2,469	1	52	111	14,153
1824	17	2,234	...	...	126	15,739
1825	24	3,003	5	1189	168	20,287
1826	72	8,638	4	404	248	28,958
1827	28	3,376	2	408	275	32,490
1828	30	2,039	1	246	293	32,032
1829	16	1,751	...	...	304	32,283
1830	18	1,745	1	481	315	33,444
1831	31	2,749	5	1687	347	37,445
1832	33	2,851	5	1239	380	41,669
1833	33	2,928	3	1017	415	45,017
1834	36	5,128	3	628	462	50,735
1835	86	10,924	2	375	538	60,520
1836	63	8,758	6	942	600	67,969
1837	78	11,669	4	478	668	78,288
1838	84	9,569	3	288	722	82,716
1839	62	6,139	3	383	770	86,731
1840	74	10,178	3	461	824	95,807
1841	48	11,363	6	1028	856	104,845
1842	58	13,716	9	1215	906	118,930
1843	46	6,129	7	610	942	121,455
1844	65	6,113	8	817	988	125,675
1845	65	10,894	8	1056	1012	131,202
1846	77	15,956	11	1216	1070	144,784
1847	103	16,170	12	1613	1154	146,557
1848	114	15,334	14	1142	1253	158,078
1849	68	12,498	12	982	1296	167,310
1850	68	14,584	13	943	1350	187,631
1851	78	22,723	10	804	1386	204,654
1852	104	30,742	8	1050	1414	223,616
1853	153	48,215	9	793	1534	264,336
1854	174	64,255	15	2191	1708	326,452
1855	233	81,018	30	3844	2010	408,290
1856	229	57,573	Returns not complete.			

The British Government possesses 324 Screw Steam Vessels of all sorts (including 154 Screw Gun-boats) and 109 Paddle Steamers; making a total of 433 Steam Vessels.

PARTICULARS OF TRIAL TRIPS OF THE PENINSULAR AND ORIENTAL STEAM NAVIGATION COMPANY'S STEAMERS.

CORRECTED TO SEPTEMBER 15, 1857. (*Communicated by* JAMES ALLAN, ESQ.)

(Vessels marked thus*, are now in course of construction, and the dimensions and tonnage here inserted are builders'.)

Name of Vessel.	Length between Perpendiculars.	Extreme Breadth.	Register Tonnage.	Draught of Water Forward.	Draught of Water Aft.	Mean Draught.	Area of Midship Sec. at this Draught.	Displacement at same.	Description of Engines.	Horses' Power.	Horse-Power, indicated.	Diameter of Cylinders.	Length of Stroke.	Diameter of Screw.	Pitch of Screw.	Length of Screw.	Number of Blades to Screw.	Revolutions of Engines per minute.	Revolutions of Screw.	Pressure per square inch.	Vacuum.	Average Speed at same.	Weights on Board.
	ft.	ft.	Tns.	ft. in.	ft. in.	ft. in.	sq. ft.	Tns.				in.	ft. i.	ft. in.	ft. in.	ft. i.				lbs.	in.	Knots	Tns.
Aden	225 15/16	29 1/16	812	13 4	14 4	13 10	302 0	1176	Direct-action trunk	210	954	44½	4 0	14 0	26 0	2 8	3	53 bare.	53	21	27	12·519	420
Alhambra	209 3/16	27 1/16	642	10 4	12 9	11 6	267 5	840	Direct-action, two piston rods	140	454	50¼	3 0	11 0	14 0	1 8	3	34	34	18	24	10·558	220
Alma	288 1/16	37 7/16	2164	18 0	19 3	19 0	511 6	2840	Oscillating	450	1445	78	5 0	16 3	21–24	2 4	3	29	..	16	26½	12·13	727
Ava	267 3/16	35 7/16	1373	15 3	15 9	15 6	401 8	2022	Trunk	320	1056	70	4 0	14 0	19 6	2 2	2	30	..	17	26½	12·439	602
Azof	214 1/16	27 7/16	700	12 9	14 5	13 7	297 9	1011	Direct-action	180	348	42	3 6	13 0	19 6	2 2	3	57	57	20	..	10·030	..
Bengal	295 5/16	38 5/16	2185	15 9	16 0	15 6	478 4	..	Beam, with gearing	465	1084	80	5 0	14 3	18–22	2 3	3	26–27	..	12	26–27	11·123	520
Benares*	274	38 5/16	1978						Direct-action	400		70	3 0	15 0	24 0	2 4	3						
Cadiz	226 5/16	28 1/16	816	11 10	12 11	12 4	262 7	908	Direct, with gearing	220	450	56	4 0	12 0	16–19	2 1	3	29 bare.	..	11	26½	11·597	..
Candia	317 5/16	40 5/16	1982	18 2½	19 7	18 11	542 3		Trunk, geared	450	1490	71	4 0	15 6	21 0	2 2	3	33	..	20	26½	12·443	955
Ceylon*	290	41	2373						Direct-action	450		72	3 0	16 4	20 0								
Chusan	190	29 5/16	699	9 0	11 0	10 0	..	..	Direct-action, oscillating cylin.	80	..	39	2 0	9 8	16 0 About	2 8	3	74	74	..	27	9·068	..
Colombo	286 11/16	36	1864	18 0	18 3½	18 1½	505 1	..	Beam, with gearing	450	1463	72	5 6	15 0	18 0	2 6	2	26½	..	..	26½–27	12·434	732
Douro	226 5/16	28 5/16	810	11 10	12 10	12 4	262 7	908	Direct, with gearing	220	..	56	4 0	12 0 Padd. w.	16–19	2 1	3	29	..	11	26½	11·120	273
Ganges	235 3/16	29 4/16	1190	..	..	12 4	334 3	1559	Direct-action	470	1162	77	6 6	28 0	..	..	..	18½	..	11	28bare	..	..
Granada*	188	27 2/16	678	..	..	..	..	..	Direct-action	160	..	45	2 6	11 8	23 0	2 6	3	..	..	..	..	..	..
Himalaya†	340	44 5/16	3438	15 6	18 5	16 11½	556 6	3260	Direct-action	700	2050	84 324	77·2	3 6	18 0	28 0	4 8	2	abt55	55	14	26	13·900	..

† Sold to Government.

Name of Vessel.	Length between Perpendiculars.	Extreme Breadth.	Register Tonnage.	Draught of Water Forward.	Draught of Water Aft.	Mean Draught.	Area of Midship Sec. at this Draught.	Displacement at same.	Description of Engines.	Horses' Power.	Horse-Power, indicated.	Diameter of Cylinders.	Length of Stroke.	Diameter of Screw.	Pitch of Screw.	Length of Screw.	Number of Blades to Screw.	Revolutions of Engines per minute.	Revolutions of Screw.	Pressure per square inch.	Vacuum.	Average Speed at same.	Weights on Board.
	ft.	ft.	Tns.	ft. in.	ft. in.	ft. in.	sq.ft.	Tns.				in.	ft. i.	ft. in.	ft. in.	ft. i.	ft. i.			lbs.	in.	Knots	Tns.
Indus	241 3/10	34 1/10	1950	17 3	16 10	17 0	536 9	..	Direct-action, oscillating cylin.	450	1367	75	7 0	Padd. w. 28 6	..	..	..	..	..	12	26	10 full	486
Madras	232 9/10	31 6/10	1185	13 8	14 4	14 0	339 6	1381	Beam, with gearing	275	754	62	5 0	14 6	18–20	2 2	3	26½	..	10	..	11·177	475
Manilla	178 1/10	26 3/10	646	7 0	11 0	9 0	..	..	Trunk, geared	60	200	30	2 3	11 0	9 6	1 6	3	44	..	16	27	9·025	124
Nemesis*	200	41	2373	..	..	..	..	..	Direct, with gearing	600	..	81	4 6	18 0	23 0	3 0	3	..	..	..	..	..	..
Norna	242 4/10	28 4/10	969	11 7	12 8	12 1	253 0	908	Direct-action	230	..	56	4 0	12 0	17 0	2 1	3	30½	30½	11	27	11·948	..
Northam*	273 5/10	34 4/12	1600	..	..	..	..	..	Direct-action	350	..	64	3 0	15 6	..	..	..	..	..	..	..	..	..
Nubia	289 5/10	38	2095	19 6	17 3	18 4	514 4	2689	Oscillating	450	..	78	5 0	16 3	21–24	2 4	2	25½	..	13	25	12·149	770
Ottawa	238 5/10	29 3/10	1274	13 7	15 0	14 3½	338 0	1513	Oscillating, gear.	200	700	54	4 0	13 3	15 0	2 2	2	33	66	17	26	10·300	614
Pera	303 3/10	42 1/10	2014	17 11	18 3½	18 1	548 4	2831	Trunk, geared	450	1373	75 & 70⅔ mean.	4 0	15 6	21 0	2 4	3	32½	65	19½	25	12·633	700
Rajah	163 6/10	24	537	8 5	12 6	10 5½	209 8	..	Single trunk, grd.	80	..	39	2 3	9 0	about 11	1 6	2	38½	..	20	26½–27	9·877	227
Ripon	231 5/10	33 2/10	1925	16 2	15 10	16 0	503 6	..	Direct-action, oscillating cylin.	450	..	75	7 0	Padd. w. 28 6	..	..	..	14½	..	9	26	10·002	417
Salsette*	274	38 6/12	1978						Direct-action	400		70	3 0	15 0	24 0	2 4	3						
Simla	330 4/10	37 1/10	2440	18 0	17 0	17 6	517 3	..	Direct, with gearing	630	..	90	6 0	18 0	21–24	4 0	3	18½	60	16	26½	13·350	..
Singapore	235 3/10	29 4/10	1190	11 11	12 9	12 4	334 3	1559	Direct-action, oscillating cylin.	470	1122	77	6 6	Padd. w. 28 0	..	..	..	18	..	13	27	11·931	..
Sultan	231	32	1124	10 3½	11 5½	10 10½	270 0	1218	Direct-action, trunk	210	767	42	4 0	13 0	26 0	2 8	3	55	55	12½	27½	10·047	337
Tartar	172 1/10	22 6/10	803	6 5	7 5	6 11	..	..	Trunk	155	557	50⅔	3 3	Padd. w. 16 0	..	..	..	..	..	16	27	12·158	..
Valetta	225	27 6/10	769	12 7	13 0	12 9½	..	..	Oscillating	400	1272	72	7 0	Padd. w. 32 6	..	..	..	18½ bare.	..	15	26	13·597	186
Vectis	228	29 1/10	785	12 4	12 8	12 6	..	..	Ditto	400	..	72	7 0	Padd. w. 32 6	..	..	..	..	..	15	..	12·411†	173

† Blowing a gale, and heavy sea on.

TABLE No. XI.

AVERAGE SPEEDS OF ROYAL MAIL STEAMERS IN THE YEAR 1857.

Route.	Vessel's Name.	Screw or Paddle.	Gross Tonnage.	Nominal Horse Power.	Date of Run.	Station.	Length of Run.	Average Speed per Hour.	Knots Run for one Ton of Coals.
							Knts	Knots	Knts
Mediterranean.	Pera . .	Screw	2013	450	Jan. 1857	Southampton to Alexandria and back	5902	11·28	
	Pera . .	,,	,,	,,	March ,,	Ditto Ditto	,,	10·56	
	Pera . .	,,	,,	,,	May ,,	Ditto Ditto	,,	11·03	
	Pera . .	,,	,,	,,	June ,,	Ditto Ditto	,,	9·88	4·89
	Colombo .	Screw	1864	450	April ,,	Ditto Ditto	,,	10·97	
	Colombo .	,,	,,	,,	May ,,	Ditto Ditto	,,	11·22	
	Colombo .	,,	,,	,,	July ,,	Ditto Ditto	,,	11·09	5·36
	Indus . .	Paddle	1950	450	April ,,	Ditto Ditto	,,	9·41	
	Indus . .	,,	,,	,,	June ,,	Ditto Ditto	,,	9·37	4·17
	Indus . .	,,	,,	,,	July ,,	Ditto Ditto	,,	8·94	
	Etna . .	Screw	2220	550	. . . .	Southampton to Malta	2132	11·10	6·18
	Etna . .	,,	,,	,,	. . . .	Malta to Alex. & back	1638	11·10	5·20
Indian and China.	Alma . .	Screw	2160	450	Nov. 1856	Indian Ocean . . .	9280	10·68	
	Alma . .	,,	,,	,,	April 1857	Ditto	,,	9·43	
	Alma . .	,,	,,	,,	June ,,	Ditto	2134	11·35	8·81
	Aden . .	Screw	982	210	Jan. ,,	Ditto	2972	11·47	
	Ganges . .	Paddle	1200	470	Jan. ,,	Ditto	,,	9·17	
	Bentinck .	Paddle	2000	520	Feb. ,,	Suez to Calcutta . .	4757	8·10	
	Hindostan .	Paddle	2000	520	March ,,	Suez to Calcut. & back	9514	9·44	
	Ava . . .	Screw	1600	320	April ,,	Ditto	,,	9·31	
	Pekin . .	Paddle	1200	400	April ,,	Indian Ocean . . .	7884	1·777	
	Bengal . .	Screw	2200	470	May ,,	Suez to Calcut. & back	9514	9·39	
	Bombay .	Screw	1200	270	May ,,	Indian Ocean . . .	4636	8·21	
	Nubia . .	Screw	2090	450	July ,,	Ditto	2134	8·67	3·83
Peninsular.	Tagus . .	Paddle	800	280	July ,,	Sthmpton to Gibraltar	2448	8·16	
	Tagus . .	,,	,,	,,	July ,,	Ditto Ditto	,,	8·00	
	Tagus . .	,,	,,	,,	Aug. ,,	. . . . .	1806	8·72	7·28
	Sultan . .	Screw	1124	200	July ,,	Sthmpton to Gibraltar	2448	8·93	
	Sultan . .	,,	,,	,,	July ,,	Ditto Ditto	,,	9·67	
	Alhambra .	Screw	642	140	July ,,	Ditto Ditto	,,	7·10	
	Alhambra .	,,	,,	,,	July ,,	Ditto Ditto	,,	9·38	
	Euxine . .	Paddle	1164	420	Aug. ,,	Ditto Ditto	,,	9·95	
	Euxine . .	,,	,,	,,	Sept. ,,	Ditto Ditto	,,	9·52	4·10
West Indian.	Atrato . .	Paddle	3466	800	May ,,	Southampton to St. Thomas and back	7244	11·49	2·79
	Atrato . .	,,	,,	,,	Aug. ,,	Ditto Ditto	,,	11·59	3·08
	Orinoco. .	Paddle	2901	800	June ,,	Ditto Ditto	,,	9·71	3·14
	Parana . .	Paddle	3070	800	June ,,	To St. Thomas . . .	3622	9·40	3·06
	Parana . .	,,	,,	,,	Sept. ,,	To St. Thomas & back	7244	9·31	3.21
	Magdalena.	Paddle	2943	800	July ,,	Ditto Ditto	,,	9·45	3·12
	Tamar . .	Paddle	1963	400	. . . .	Southampton to Lisbon	866	9·84	4.9
	Tamar . .	,,	,,	,,	. . . .	Lisbon to Madeira .	535	10·49	5·09
	Tamar . .	,,	,,	,,	. . . .	Pernambuco to St. Vin.	1600	11·27	3·73
*	Terrible .	Paddle	1850	800	1846	Tetuan to Malta . .	977	10·33	5·29
*	Terrible .	,,	with 130 tons more weight		,,	Malta to Gibraltar .	990	9·25	4·76
*	Terrible .	,,	..	..	,,	. . . . .	922	9·04	5·60

* During those three trials only two of the *Terrible's* four boilers were used, and the steam was expanded in the cylinders after ½ stroke, no sail being set.

FORM OF LOG FOR A SEA-GOING STEAMER.

1.—*Observations to be made at the End of each Watch of Four Hours by the Engineer in charge.*

		Boilers.					Condensers.			Temperature of					Expansion.	Revolutions per min. Average during Watch.		Rate in Knots per hour. Average during Watch.			Remarks on the Weather, the state of the Engines, &c.
		No. of Sections in use.	No. of Fires in use.	Coals burnt during the Watch.			Average Pressure of Steam.	Saltness, by Salinometer Scale.	Height of external Barometer.	Height of Engine-Barometer, Starboard.	Height of Engine-Barometer, Larboard.	Hot well, Starboard.	Hot well, Larboard.	Engine Room.	Coal Boxes, Maximum.	Sea.	Steam expanded after—part of Stroke.	Engines.	(Wheels or) Screw.	(Wheels or) Screw.	Ship, by Patent Log.	(Wheels or) Screw.	
	Watch ending	No.	No.	cwt.	qrs.	lbs.	lbs.	sp. gr.	inches	inches	inches	deg.	deg.	deg.	deg.	deg.		No.	No	Knots.	Knots.	Knots.	
June 12	10 a.m.	3	9	95	3	6	11	1·08	29·6	26·4	26·9	105	102	75	72	64	⅛	17·5	52·5	10·12	8.8	1·32	Wind a-beam, ship rolling deep, square sails set.
,,	2 p.m.	3	9	98	2	5	9	1.08	29·7	26·6	27·2	102	98	76	74	64	⅛	19·2	57·6	11·8	10·6	1·2	Wind light, ground swell.
,,	6 p.m.	2	6	64	2	18	7·5	1·07	29·7	26·9	27·4	98	95	78	77	65	⅛	15·1	45·3	8·7	7·9	·9	Calm, sea down
	Tons	12		19	0	1	=Coals burnt during preceding 12 hours.										Averages	51·8	10·2	9·1	1·14	
June 12	10 p.m.																						
,, 13	2 a.m.																						
,,	6 a.m.																						
	Tons						Coals burnt during preceding 12 hours.										Averages						

FORM OF LOG FOR A SEA-GOING STEAMER.—*Continued.*

2.—*Observations and Reductions, from No.* 1, *to be made every twelve hours by the First Engineer, and submitted to the Captain of the Vessel.*

		Rate of the (Wheels or) Screw and Ship, in Knots per hour.			Number of Hours in which Sails were set.	Number of Hours under Steam.	Distance run from beginning of Voyage.	Indicator Horse-Power of one Engine.	Stores Consumed.				Remarks.
		Average during preceding 12 hours.		Distance run in preceding 12 Hours.					Coals.		Tallow.	Oil.	
		(Wheels) or Screw.	Ship, per Patent Log.						Burnt in the preceding 12 Hours.	Remaining in Ship.	Used in preceding 12 Hours.	Used in preceding 12 Hours.	
		knots.	knots.	knots.	hours	hours.	knots.	H. P.	tons. cwt. qrs. lbs.	tons.	lbs.	pints.	
June 12	6 p.m.	10·2	9·1	109·2	8	12	1086	346	12 19 0 1	217·6	4½	5½	
„ 13	6 a.m.												

TABLE OF THE VELOCITIES OF PADDLE WHEELS OF DIFFERENT DIAMETERS IN FEET PER MINUTE AND BRITISH STATUTE MILES PER HOUR.

DIAM.—	10 ft.		10ft. 6in.		11 ft.		11ft. 6in.		12 ft.		12ft. 6in.		13 ft.		13ft. 6in.		14 ft.		14ft. 6in.		15 ft.		15ft. 6in.		16 ft.		16ft. 6in.		17 ft.		17ft. 6in.	
Revolutions per min.	Ft. per min	Mls. per hour	Ft. per min	Mls. per hour	Ft. per min	Mls. per hour	Ft. per min	Mls. per hour	Ft. per min	Mls. per hour	Ft. per min	Mls. per hour	Ft. per min	Mls. per hour	Ft. per min	Mls. per hour	Ft. per min	Mls. per hour	Ft. per min	Mls. per hour	Ft. per min	Mls. per hour	Ft. per min	Mls. per hour	Ft. per min	Mls. per hour	Ft. per min	Mls. per hour	Ft. per min	Mls. per hour	Ft. per min	Mls. per hour
10	942	..	..	..	..	..	..	..	392	4·46	408	4·64	424	4·82	440	5·00	455	5·17	471	5·35	487	5·53	502	5·71	518	5·89	534	6·07	549	6·24
11	974	..	..	..	..	..	414	4·71	432	4·91	449	5·10	466	5·30	484	5·49	501	5·69	518	5·89	535	6·06	553	6·28	570	6·48	587	6·67	604	6·87
12	1005	..	..	..	..	..	433	4·92	552	5·14	471	5·35	490	5·57	509	5·78	527	5·99	546	6·21	565	6·42	584	6·64	603	6·85	622	7·08	641	7·28	659	7·49
13	1036	..	428	4·87	449	5·10	469	5·33	490	5·57	510	5·80	531	6·03	551	6·26	571	6·49	592	6·73	612	6·96	633	7·19	653	7·42	674	7·67	694	7·89	714	8·12
14	1068	4·99	461	5·24	483	5·49	505	5·74	527	5·99	549	6·24	571	6·49	593	6·74	615	6·99	637	7·24	659	7·49	681	7·74	703	7·99	725	8·26	747	8·49	769	8·74
15	1099	5·35	494	5·62	518	5·89	542	6·16	565	6·42	589	6·69	612	6·96	636	7·23	659	7·49	683	7·76	706	8·03	730	8·30	754	8·57	777	8·85	801	9·10	824	9·37
16	1131	5·71	527	5·99	552	6·28	578	6 57	603	6·85	628	7·14	653	7·42	678	7·71	703	7·99	729	8·28	754	8·57	779	8·85	804	9·14	829	9·44	854	9·71	879	9·99
17	1162	6·06	560	6·37	587	6·67	614	6·98	640	7·28	667	7·58	694	7·89	721	8·19	747	8·49	774	8·80	801	9·10	828	9·40	854	9·71	881	10·03	908	10·31	934	10·62
18	1194	6·42	593	6·74	622	7·07	650	7·38	678	7·71	707	8·03	735	8·35	763	8·67	791	8·99	819	9·31	848	9·64	876	9·96	904	10·28	933	10·62	961	10·92	989	11·24
19	1225	6·78	626	7·12	656	7·46	686	7·80	716	8·14	746	8·48	776	8·81	806	9·15	835	9·49	865	9·83	895	10·17	925	10·51	955	10·85	985	11·21	1014	11·53	1044	11·87
20	1256	7·14	659	7·49	691	7·85	722	8·21	754	8·57	785	8·92	817	9·28	848	9·64	879	9·99	911	10·35	942	10·71	974	11·06	1005	11·42	1036	11·80	1068	12·14	1099	12·49
21	1288	7·49	692	7·87	725	8·24	758	8·62	791	8·99	824	9·37	857	9·74	890	10·12	923	10·49	956	10·87	989	11·24	1022	11·62	1055	11·99	1088	12·39	1121	12·74	1154	13·12
22	1319	7·85	725	8·24	760	8·64	795	9·03	829	9·42	864	9·81	898	10·21	933	10·60	967	10·99	1002	11·39	1036	11·78	1071	12·17	1106	12·56	1140	12·98	1175	13·35	1209	13·74
23	1351	8·21	758	8·62	795	9·03	831	9·44	867	9·85	903	10·26	939	10 67	975	11·08	1011	11·49	1047	11·90	1084	12·31	1120	12·72	1156	13·13	1192	13·56	1228	13·96	1264	14·37
24	1382	8·57	791	8·99	829	9·42	867	9·85	904	10·28	942	10·71	980	11·14	1017	11·56	1055	11·99	1093	12·42	1131	12·85	1168	13·28	1206	13·71	1244	14·15	1281	14·56	1319	14·99
25	1413	8·92	824	9·37	864	9·81	903	10·26	942	10·71	981	11·15	1021	11·60	1060	12·05	1099	12·49	1139	12·94	1178	13·38	1217	13·83	1256	14·28	1296	14·74	1335	15·17	1374	15·62
26	1445	9·28	857	9·74	898	10·21	939	10·67	980	11·14	1021	11·60	1062	12·06	1102	12·53	1143	12·99	1184	13·46	1224	13·92	1266	14·38	1307	14·85	1348	15·32	1388	15·78	1429	16·24
27	848	9·64	800	10·12	933	10·60	975	11·08	1018	11·56	1060	12·05	1102	12·53	1145	13·01	1187	13·49	1230	13·97	1272	14·46	1314	14·94	1357	15·42	1399	15·92	1442	16·38	1484	16·87
28	879	9·99	923	10·49	967	10·99	1011	11·49	1055	11·99	1099	12·49	1143	12 99	1187	13·49	1231	13·99	1275	14·49	1319	14·99	1363	15·50	1407	15·99	1451	16·51	1495	16·99	1539	17·49
29	911	10·35	956	10·87	1002	11·39	1047	11·90	1093	12·42	1139	12·94	1184	13·46	1230	13·97	1275	14·49	1321	15·01	1366	15·53	1412	16·04	1457	16·56	1503	17·10	1549	17·60	1594	18·11
30	942	10·71	989	11·24	1036	11·78	1083	12·31	1131	12 85	1178	13·38	1225	13·92	1272	14·46	1319	14·99	1366	15·53	1413	16·06	1461	16·60	1508	17·13	1555	17·69	1602	18·20	1649	18·74
31	974	11·06	1022	11·62	1071	12·17	1120	12·72	1168	13·28	1217	13·83	1266	14·38	1314	14·94	1363	15·49	1412	16·04	1461	16·60	1509	17·15	1558	17·70	1607	18·28	1655	18·81	1704	19·36
32	1005	11·42	1055	11·99	1106	12·56	1156	13·13	1206	13·71	1256	14·28	1307	14·85	1357	15·42	1407	15·69	1457	16·56	1508	17·13	1558	17·70	1608	18·28	1658	18·87	1709	19·42	1759	19·99
33	1036	11·78	1088	12·37	1140	12·96	1192	13·55	1244	14·13	1296	14·72	1347	15·31	1399	15·90	1451	16·49	1503	17·08	1555	17·67	1607	18·26	1658	18·85	1710	19·45	1762	20·02	1814	20·61
34	1068	12·13	1121	12·74	1175	13·35	1228	13·96	1281	14·56	1335	15·17	1388	15·78	1442	16·38	1495	16·99	1549	17·60	1602	18·20	1655	18·81	1709	19·42	1762	20·04	1816	20·63	1868	21·24
35	1099	12·49	1154	13·12	1209	13·74	1264	14·37	1319	14·99	1374	15·62	1429	16·24	1484	16·87	1539	17·49	1594	18·11	1649	18·74	1704	19·36	1759	19·99	1814	20·63	1869	21·24	1924	21·86
36	1131	12·85	1187	13·49	1244	14·13	1300	14·78	1357	15·42	1413	16 06	1470	16·70	1527	17·35	1583	17·99	1640	18·63	1696	19·28	1753	19·92	1809	20·56	1866	21·22	1922	21·85	1979	22·49
37	1162	13·21	1220	13·87	1278	14·53	1336	15·19	1395	15·85	1453	16·51	1511	17·17	1569	17·83	1627	8·49	1685	19·15	1743	19·81	1801	20·47	1860	21·13	1918	21·81	1976	22·45	2034	23·11
38	1194	13·56	1253	14·24	1313	14·92	1372	15·60	1432	16·28	1492	16·95	1552	17·63	1611	18·31	1671	18·99	1731	19·67	1790	20·35	1850	21·02	1910	21·70	1969	22·40	2029	23·06	2089	23·74
39	1225	13 92	1286	14·61	1347	15·31	1409	16·01	1470	16·70	1531	17·40	1592	18·10	1654	18·79	1715	19·49	1776	20·19	1838	20·88	1899	21·58	1960	22·27	2021	22·99	2083	23·67	2144	24·36
40	1256	14·26	1319	14·99	1382	15·71	1445	16·42	1508	17·13	1570	17·85	1633	18·56	1696	19·28	1759	19·99	1822	20·70	1885	21·42	1947	22·13	2010	22·85	2073	23·58	2136	24·27	2199	24·99
41	1288	14·62	1352	15·37	1416	16·10	1481	16·83	1545	17·56	1610	18·29	1674	19·03	1739	19·76	1803	20·49	1867	21·22	1932	21·95	1996	22·68	2061	23·42	2125	24·17	2189	24·88	2254	25·61
42	1319	14·98	1385	15·74	1451	16·49	1517	17·24	1583	17·99	1649	18·74	1715	19·49	1781	20·24	1847	20·99	1913	21·74	1979	22·49	2045	23·24	2111	23·99	2177	24·76	2243	25·49	2308	26·24
43	1351	15·33	1418	16·12	1486	16·88	1553	17·65	1621	18·42	1688	19·19	1756	19·95	1824	20·72	1891	21·49	1958	22·26	2026	23·02	2093	23·79	2161	24·56	2229	25·33	2296	26·09	2364	26·86
44	1382	15·69	1451	16·49	1520	17·27	1589	18·06	1659	18·85	1728	19·63	1797	20·42	1866	21·20	1935	21·99	2004	22·77	2073	23·56	2144	24·34	2211	25·13	2281	25·92	2350	26·70	2419	27·49
45	1413	16·05	1484	16·87	1555	17·67	1625	18·47	1696	19·28	1767	20·08	1838	20·88	1908	21·68	1979	22·49	2050	23·29	2120	24·09	2191	24·90	2262	25·70	2332	26·50	2403	27·31	2474	28·11
46	1445	16·40	1517	17·24	1589	18·06	1662	18·88	1734	19·70	1806	20·52	1878	21·35	1951	22·17	2023	22·99	2095	23·81	2167	24·63	2240	25·45	2312	26·27	2384	27·09	2456	27·91	2529	28·74
47	1476	16·76	1550	17·61	1624	18·45	1698	19·29	1772	20·13	1845	20·97	1919	21 81	1993	22·65	2067	23·49	2141	24·33	2215	25·17	2289	26·00	2362	26·84	2436	27·68	2510	28·52	2584	29·36
48	1508	17·12	1583	17·99	1658	18·85	1734	19·70	1803	20·56	1884	21·42	1960	22·27	3035	23·13	2111	23·99	2186	24·84	2269	25·70	2337	26·56	2412	27·41	2488	28·27	2563	29·13	2639	30·00
49	1539	17·47	1616	18·36	1693	19·24	1770	20·11	1847	20·99	1924	21·86	2001	22·74	2078	23·61	2155	24·49	2232	25·36	2309	26·24	2386	27·11	2463	27·99	2540	28·86	2617	29·74		
50	1571	17·83	1649	18·74	1727	19·64	1806	20·52	1884	21·42	1963	22·31	2042	23·20	2120	24·09	2129	24·99	2277	25·87	2355	26·77	2435	27·67	2513	28·56	2592	29·45				

DIAM.-	— 18 ft.		18 ft. 6 in.		19 ft.		19 ft. 6 in.		20 ft.		20 ft. 6 in.		21 ft.		21 ft. 6 in.		22 ft.		22 ft. 6 in.		23 ft.		23 ft. 6 in.		24 ft.		24 ft. 6 in.		25 ft.		25 ft. 6 in.	
Revolutions per min.	Ft. per min	Mls. per hour	Ft. per min	Mls. per hour	Ft. per min	Mls. per hour	Ft per min	Mls. per hour	Ft per min	Mls. per hour	Ft. per min	Mls. per hour	Ft. per min	Mls. per hour	Ft. per min	Mls. per hour	Ft. per min	Mls per hour	Ft. per min	Mls. per hour	Ft. per min	Mls. per hour	Ft. per min	Mls per hour	Ft. per min	Mls. per hour	Ft. per min	Mls. per hour	Ft. per min	Mls. per hour	Ft. per min	Mls. per hour
10	565	6·42	531	6·60	597	6·78	612	6·96	628	7·14	644	7·32	659	7·49	675	7·67	691	7·85	707	8·03	722	8·21	738	8·39	754	8·57	769	8·74	785	8·92	801	9·10
11	622	7·07	639	7·26	656	7·46	674	7·65	691	7·85	708	8·05	725	8·24	743	8·44	760	8·64	777	8·83	795	9·03	812	9·23	829	9·42	846	9·62	864	9·81	881	10·01
12	678	7·71	697	7·92	716	8·14	735	8·35	754	8·57	773	8·78	791	8·99	810	9·21	829	9·42	848	9·64	865	9·85	886	10·06	905	10·28	923	10·49	942	10·71	961	10·92
13	735	8·35	755	8·58	776	8·82	796	9·05	817	9·28	837	9·51	857	9·74	878	9·98	898	10·21	919	10·44	937	10·67	959	10·90	980	11·14	1000	11·37	1021	11·60	1041	11·83
14	791	8·99	813	9·24	835	9·49	857	9·74	879	9·99	901	10·24	923	10·49	945	10·74	967	10·99	989	11·24	1009	11·49	1033	11·74	1055	11·99	1077	12·24	1099	12·49	1122	12·74
15	848	9·64	871	9·90	895	10·17	919	10·44	942	10·71	966	10·97	989	11·24	1013	11·51	1036	11·78	1060	12·05	1082	12·31	1107	12·58	1139	12·85	1154	13·12	1178	13·38	1201	13·65
16	904	10·28	930	10·56	955	10·85	980	11·14	1005	11·42	1030	11·71	1055	11·99	1080	12·28	1106	12·56	1131	12·85	1154	13·13	1181	13·42	1206	13·71	1231	13·99	1256	14·28	1281	14·56
17	961	10·92	988	11·22	1014	11·53	1041	11·83	1068	12·14	1095	12·44	1121	12·74	1148	13·05	1175	13·35	1201	13·65	1226	13·96	1255	14·26	1281	14·56	1308	14·87	1335	15·17	1362	15·47
18	1018	11·56	1046	11·89	1074	12·21	1102	12·53	1131	12·85	1159	13·17	1187	13·49	1215	13·81	1244	14·13	1272	14·46	1298	14·78	1329	15·10	1357	15·42	1385	15·74	1413	16·06	1442	16·38
19	1074	12·21	1104	12·55	1134	12·88	1164	13·22	1194	13·56	1223	13·90	1253	14·24	1283	14·58	1313	14·92	1343	15·26	1371	15·60	1402	15·94	1432	16·28	1462	16·62	1492	16·95	1522	17·29
20	1131	12·85	1162	13·21	1194	13·56	1225	13·92	1256	14·28	1288	14·63	1319	14·99	1351	15·35	1382	15·71	1413	16·06	1445	16·42	1476	16·78	1508	17·13	1539	17·49	1571	17·85	1602	18·20
21	1187	13·49	1220	13·17	1253	14·24	1286	14·62	1319	14·99	1352	15·37	1385	15·74	1418	16·12	1451	16·49	1484	16·87	1517	17·24	1550	17·61	1583	17·99	1616	18·36	1649	18·74	1683	19·11
22	1244	14·13	1278	14·53	1313	14·92	1347	15·31	1382	15·71	1417	16·10	1451	16·49	1486	16·88	1520	17·28	1555	17·67	1589	18·06	1624	18·45	1658	18·85	1693	19·24	1728	19·63	1763	20·02
23	1300	14·78	1336	15·19	1373	15·60	1409	16·01	1445	16·42	1481	16·83	1517	17·24	1553	17·65	1589	18·06	1625	18·47	1662	18·88	1698	19·29	1734	19·70	1770	20·11	1806	20·52	1843	20·94
24	1357	15·42	1395	15·85	1432	16·28	1470	16·70	1508	17·13	1545	17·56	1583	17·99	1621	18·42	1658	18·85	1696	19·28	1734	19·70	1772	20·13	1809	20·56	1847	20·99	1885	21·42	1923	21·85
25	1413	16·06	1453	16·51	1492	16·95	1531	17·40	1571	17·85	1610	18·29	1649	18·74	1688	19·19	1728	19·63	1767	20·08	1806	20·52	1845	20·97	1885	21·42	1924	21·86	1963	22·31	2003	22·76
26	1470	16·70	1511	17·17	1552	17·63	1592	18·20	1633	18·56	1674	19·03	1715	19·49	1756	19·95	1797	20·42	1838	20·88	1878	21·35	1919	21·81	1962	22·27	2001	22·74	2042	23·20	2084	23·67
27	1527	17·35	1569	17·83	1611	18·31	1654	18·79	1696	19·28	1739	19·76	1781	20·24	1823	20·72	1866	21·20	1908	21·68	1951	22·17	1993	22·65	2035	23·13	2078	23·61	2120	24·09	2164	24·58
28	1583	17·99	1627	18·49	1671	18·99	1715	19·49	1759	19·99	1803	20·49	1847	20·99	1891	21·49	1935	21·99	1979	22·49	2023	22·99	2067	23·49	2111	23·99	2155	24·49	2199	24·99	2244	25·49
29	1640	18·63	1685	19·15	1713	19·67	1776	20·19	1822	20·70	1867	21·22	1913	21·74	1958	22·26	2004	22·77	2050	23·29	2095	23·81	2141	24·33	2186	24·84	2232	25·36	2277	25·88	2324	26·40
30	1696	19·28	1743	19·81	1790	20·35	1838	20·88	1885	21·42	1932	21·95	1979	22·49	2026	23·02	2073	23·56	2120	24·09	2167	24·63	2215	25·17	2262	25·70	2309	26·24	2356	26·77	2403	27·31
31	1753	19·92	1801	20·47	1850	21·02	1899	21·58	1947	22·13	1996	22·68	2045	23·24	2094	23·79	2142	24·34	2191	24·90	2240	25·45	2288	26·00	2337	26·56	2386	27·11	2434	27·66	2483	28·22
32	1809	20·56	1860	21·13	1910	21·70	1960	22·27	2013	22·85	2061	23·42	2111	23·99	2161	25·56	2211	25·13	2262	25·70	2312	26·27	2362	26·84	2412	27·41	2463	27·99	2513	28·56	2563	29·13
33	1866	21·20	1918	21·79	1969	22·38	2021	22·97	2073	23·56	2125	24·15	2177	24·74	2229	25·33	2281	25·92	2332	26·50	2384	27·09	2436	27·68	2488	28·27	2540	28·86	2592	29·45	2643	30·04
34	1922	21·85	1976	22·45	2029	23·06	2083	23·67	2136	24·27	2189	24·88	2243	25·49	2296	26·03	2350	26·70	2403	27·31	2456	27·91	2510	28·52	2563	29·13	2617	29·74	2670	30·34		
35	1979	22·49	2034	23·11	2089	23·74	2144	24·36	2199	24·99	2254	25·61	2309	26·24	2364	26·86	2419	27·49	2474	28·11	2529	28·74	2584	29·36	2639	29·98	2694	30·61				
36	2035	23·13	2092	23·77	2149	24·42	2205	25·06	2262	25·70	2318	26·34	2375	26·99	2431	27·63	2488	28·27	2554	28·91	2601	29·56	2657	30·20	2714	30·84						
37	2092	23·77	2150	24·43	2208	25·08	2266	25·75	2324	26·42	2383	27·08	2441	27·74	2499	28·40	2557	29·06	2615	29·72	2673	30·38										
38	2149	24·42	2208	25·09	2268	25·77	2328	26·45	2387	27·13	2447	27·81	2507	28·49	2566	29·16	2626	29·84	2686	30·52												
39	2205	25·06	2266	25·75	2328	26·45	2389	27·15	2450	27·84	2511	28·54	2573	29·24	2634	29·93	2695	30·63														
40	2262	25·70	2324	26·42	2387	27·13	2450	27·84	2513	28·56	2576	29·27	2639	29·99	2701	30·70																
41	2318	26·34	2383	27·08	2447	27·81	2511	28·54	2576	29·27	2640	30·00	2705	30·74																		
42	2375	26·99	2441	27·74	2507	28·49	2573	29·24	2639	29·98	2705	30·73																				
43	2431	27·63	2499	28·40	2566	29·16	2634	29·93	2701	30·70																						
44	2488	28·27	2557	28·96	2626	29·84	2691	30·63																								
45	2544	28·91	2615	29·62	2686	30·52																										
46	2601	29·56	2673	30·28																												
47	2657	30·20																														
48																																
49																																
50																																

TABLE OF THE VELOCITIES OF PADDLE WHEELS, ETC.—*Continued.*

Diam.	26 ft.		26 ft. 6 in.		27 ft.		27 ft. 6 in.		28 ft.		29 ft.		30 ft.		31 ft.		32 ft.		33 ft.		34 ft.		35 ft.		40 ft.	
Revolutions per minute.	Ft. per min.	Mls. per hour.	Ft. per min.	Mls. per hour.	Ft. per min.	Mls. per hour.	Ft. per min.	Mls. per hour.	Ft. per min.	Mls. per hour.	Ft. per min.	Mls. per hour.	Ft. per min.	Mls. per hour.	Ft. per min.	Mls. per hour.	Ft. per min.	Mls. per hour.	Ft. per min.	Mls. per hour.	Ft. per min.	Mls. per hour.	Ft. per min.	Mls. per hour.	Ft. per min.	Mls. per hour.
5	408	4·64	416	4·73	424	4·82	432	4·91	440	4·99	455	5·18	471	5·35	487	5·52	503	5·71	518	5·89	529	6·01	550	6·25	628	7·14
6	490	5·57	499	5·67	509	5·78	518	5·89	527	5·99	547	6·21	565	6·42	584	6·63	603	6·85	622	7·07	635	7·12	660	7·50	750	8·57
7	571	6·49	582	6·62	593	6·74	604	6·87	615	6·99	638	7·25	660	7·49	682	7·73	704	8·09	726	8·25	741	8·41	770	8·75	880	9·99
8	653	7·42	666	7·57	678	7·71	691	7·85	703	7·99	729	8·28	754	8·56	779	8·84	804	9·23	829	9·42	846	9·62	880	9·99	1005	11·42
9	735	8·35	749	8·51	763	8·67	777	8·83	791	8·99	820	9·32	848	9·63	876	9·94	905	10·37	933	10·60	952	10·82	990	11·24	1131	12·85
10	817	9·28	832	9·46	848	9·64	864	9·81	879	9·98	911	10·36	942	10·71	974	11·06	1005	11·42	1037	11·78	1058	12·02	1099	12·49	1257	14·28
11	889	10·21	915	10·40	933	10·60	950	10·80	967	10·98	1002	11·39	1037	11·78	1071	12·16	1106	12·56	1140	12·96	1164	13·22	1209	13·74	1382	15·71
12	980	11·13	999	11·35	1018	11·56	1036	11·78	1055	11·98	1093	12·43	1131	12·85	1169	13·27	1206	13·70	1244	14·14	1270	14·42	1319	14·99	1508	17·13
13	1062	12·06	1082	12·30	1102	12·53	1123	12·76	1143	12·98	1184	13·47	1225	13·92	1266	14·37	1307	14·84	1348	15·31	1376	15·63	1429	16·24	1634	18·56
14	1143	12·99	1165	13·24	1187	13·49	1209	13·74	1231	13·98	1275	14·50	1319	14·99	1363	15·48	1407	15·98	1451	16·49	1481	16·83	1539	17·49	1759	19·99
15	1225	13·92	1248	14·19	1272	14·46	1296	14·72	1319	14·97	1367	15·54	1414	16·06	1461	16·58	1508	17·13	1555	17·67	1587	18·03	1649	18·74	1885	21·42
16	1307	14·85	1332	15·13	1357	15·42	1382	15·71	1407	15·97	1458	16·58	1508	17·13	1558	17·69	1608	18·27	1659	18·85	1693	19·23	1759	19·99	2011	22·85
17	1388	15·78	1415	16·08	1442	16·38	1468	16·69	1495	16·97	1542	17·62	1602	18·20	1656	18·79	1709	19·41	1762	20·03	1799	20·43	1869	21·24	2136	24·27
18	1470	16·70	1498	17·03	1527	17·35	1555	17·67	1583	17·97	1640	18·66	1696	19·27	1753	19·90	1809	20·55	1866	21·20	1905	21·64	1979	22·49	2262	25·70
19	1552	17·63	1581	17·97	1611	18·31	1641	18·65	1671	18·97	1731	19·70	1791	20·34	1850	21·00	1910	21·69	1970	22·38	2010	22·84	2089	23·74	2388	27·13
20	1633	18·56	1665	18·92	1696	19·28	1728	19·63	1759	19·96	1822	20·72	1885	21·42	1948	22·12	2011	22·84	2073	23·56	2116	24·04	2199	24·99	2513	28·56
21	1715	19·49	1748	19·86	1781	20·24	1815	20·61	1847	20·98	1913	21·75	1979	22·49	2045	23·22	2111	23·98	2177	24·74	2222	25·24	2309	26·24	2639	29·99
22	1797	20·41	1831	20·81	1866	21·20	1900	21·60	1935	21·96	2004	22·78	2073	23·56	2143	24·33	2212	25·12	2281	25·92	2328	26·44	2419	27·49	2765	31·41
23	1878	21·34	1914	21·76	1951	22·17	1987	22·58	2023	22·96	2095	23·81	2168	24·63	2240	25·43	2312	26·26	2384	27·09	2434	27·65	2529	28·74	2890	32·84
24	1960	22·27	1998	22·70	2035	23·13	2073	23·76	2111	23·96	2186	24·84	2262	25·70	2337	26·54	2413	27·40	2488	28·27	2539	28·85	2639	29·99	3016	34·27

Note. The British statute mile contains 5280 feet, and the geographical nautical mile (commonly called knot) contains 6082·66 feet; being in the relative proportion of 60 to 69, nearly. Hence, to reduce the above velocities into *knots*, we must multiply by 60 and divide by 69, or multiply by ·868. If the result be required in *knots, in place of statute miles*, for a comparison of the velocities of the same paddle wheel at different speeds of the engine, it will then be most convenient to reduce the effective diameter of the wheel into nautical feet by multiplying it by ·868, and then reading off the velocities corresponding to this reduced diameter in the table, as *knots*.

1.—SHOWING THE ECONOMIC VALUES OF DIFFERENT COALS.

Names of the Coals experimented upon.	Economic evaporating power, or number of lbs. of water evaporated from 212° by 1 lb. coal.	Weight of 1 cubic foot of the coal as used for fuel,	Weight of 1 cubic foot as calculated from the density.	Ratio of B to C, or of the economical to the theoretical weight.	Difference per cent. between theoretical and economical weights.	Space occupied by 1 ton, in cubic feet (economic weight).	Results of experiments on cohesive power of coals, percentage of large coals.	Evaporating power of the coal after deducting for the combustible matter in the residue.	Weight of water evaporated from 212° by 1 cubic foot of coal.	Rate of evaporation, or number of lbs. water evaporated per hour. mean.
WELSH COALS.	**A.**	**B.**	**C.**	**D.**	**E.**	**F.**	**G.**	**H.**	**I.**	**K.**
Craigola	9·35	60·166	81·107	·742	34·8	37·23	49·3	9·66	581·20	441·48
Anthracite (Jones & Co.)	9·46	58·25	85·786	·679	47·26	38·45	68.5	9·7	565·02	409·37
Oldcastle Fiery Vein	8·94	50·916	80·42	·633	57·946	43·99	57·7	..	455·18	464.30
Ward's Fiery Vein	9·40	57·433	83·85	·685	46·0	39·0	46·5	10·6	508·78	529·90
Binea Coal	9·94	57·08	81·357	·702	42·53	39·24	51·2	10·3	587·92	496·95
Llangennech	8·86	56·93	81·85	·695	43·76	39·34	53·5	4·2	523·75	376·22
Pentrepoth	8·72	57·72	81·73	·705	40·17	38·80	46·5	8·98	518·32	381·50
Pentrefellin	6·30	66·166	84·726	·781	28·051	33·85	52·7	7·4	489·62	247·24
Duffryn	10·14	53·23	62·72	·643	58·43	42·09	56·2	11·80	540·12	409·32
Mynydd Newydd	9·52	56·33	81·73	·689	45·09	39·76	53·7	10·59	536·26	470·69
Three-quarter Rock Vein	8·84	56·888	83·60	·674	48·26	39·72	52·7	..	498·46	486·86
Cwm Frood Rock Vein	8·70	55·277	78·299	·706	41·648	40·52	72·5	9·35	480·90	379·80
Cwm Nanty-gros	8·42	56·0	79·859	·701	42·60	40·0	55·7	8·82	471·52	404·16
Resolven	9·53	58·66	82·354	·713	40·39	38·19	35·0	10·44	559·02	390·25
Pontypool	7·47	55·7	82·35	·676	47·845	40·216	57·5	8·04	460·07	250·40
Bedwas	9·79	50·5	82·6	·611	63·565	44·32	54·0	9·99	494·39	476·96
Ebbw Vale	10·21	53·3	78·81	·676	45·98	42·26	45·0	10·64	544·19	460·22
Porthmawr	7·53	53·0	86·722	·614	62·7	42·02	60·0	7·75	401·34	347·44
Coleshill	8·00	53·0	90·463	·658	51·85	42·26	62·0	8·34	424·0	406·41
Thomas's Merthyr	10·16	53·0	82·29	·644	55·26	42·26	55·5	10·72	538·48	520·8
Nixon's Merthyr	9·96	51·7	82·29	·628	59·16	43·32	64·5	10·70	514·93	511·4
Hill's Plymouth Work	9·75	51·2	84·78	·603	65·68	43·74	64·0	10·18	599·20	531·6
Aberdare Co.'s Merthyr	9·73	49·3	81·73	·603	65·78	45·43	74·5	10·27	479·68	489·5
Gadley nine-feet Seam	9.56	54·8	83·16	·658	51·75	40·87	76·0	10·46	523·88	517·3
Neath Abbey	9·38	59·3	83·57	·709	40·92	37·77	50·0	9·65	556·23	546.1
Gadley four-feet Seam	9·29	51·6	82·79	·623	60·44	43·41	68.5	10·73	479·36	400·0
Llynvi	9·19	53·3	80·35	·663	50·56	42·02	..	9·58	429·82	399·5
Rock Vawz	7·68	55·0	80·21	·685	45·83	40·72	65·5	7·88	422·40	397·5
LANCASHIRE COALS.										
Balcarras Arley	8·83	50·5	78·17	·646	54·79	44·35	76·0	9·09	445·91	454·1
Blackley Hurst	8·81	48·0	78·90	·608	64·37	46·60	65·0	9·00	422·88	500·8
Blackbrook Little Delf	8·29	51·0	78·16	·652	53·25	43·92	61·5	8·58	422·79	440·4
Rushy Park Mine	8·08	47·0	80·04	·587	70·31	47·65	67·0	8·35	379·76	419·1
Blackbrook Rushy Park	8·02	55·6	80·15	·689	44·93	40·50	80·5	8·26	443·50	481·2
Johnson & Wirthington's Rushy Park	8·01	50·0	80·10	·624	60.20	44·80	69·0	8·16	400·50	454·5
Laffak Rushy Park	7·98	52·6	84·07	·625	59·82	42·85	75·5	8·16	419·74	435·0
Balcarres Haigh Yard	7·90	50·8	80·10	·634	57·37	44·13	80·0	8·23	401·32	398·3
Cannel (Wigan)	7·70	48·3	76·80	·628	59·00	46.37	95·3	8·06	371·91	381·1
Balcarras Lindsay	7·44	51·1	78·61	·650	53·83	43·83	70·0	7·58	380·18	431·5

Names of the Coals experimented upon.	Economic evaporating power, or number of lbs. of water evaporated from 212° by 1 lb. coal.	Weight of 1 cubic foot of the coal as used for fuel.	Weight of 1 cubic foot as calculated from the density.	Ratio of B to C, or of the economical to the theoretical weights.	Difference per cent. between theoretical and economical weights.	Space occupied by 1 ton, in cubic feet (economic weight).	Results of experiments on cohesive power of coals, percentage of large coals.	Evaporating power of the coal, after deducting for the combustible matter in the residue.	Weight of water evaporated from 212° by 1 cubic foot of coal.	Rate of evaporation, or number of lbs. water evaporated per hour. mean.
LANCASHIRE COALS.	A.	B.	C.	D.	E.	F.	G.	H.	I.	K.
Balcarras five-feet .	7·21	49·0	79·11	·619	61·44	45·71	44·5	7·35	353·29	487·5
Johnson&Wirthington's, Sir John .	6·32	51·6	81·73	·631	58·39	43·13	82·0	6·62	326.11	362·7
NEWCASTLE COALS.										
Andrew's House (Tanfield) . .	9·39	52·1	78·86	·360	51·36	42·99	..	9·80	489·21	351·2
Newcastle Hartley	8·23	50·5	80·27	·629	58·95	44·35	78·5	8·55	415·61	308·0
Hedley's Hartley .	8·16	52·0	81·79	·635	57·28	43·07	85·5	8·71	424·62	300·8
Bate's West Hartley	8·04	50·8	78·17	·649	53·87	44·13	69·5	8·26	408·43	406.8
Buddle's West Hartley . .	7·82	50·6	77·11	·656	52·39	40·09	80·0	8·01	395·69	413·3
Hasting's Hartley .	7·77	48·5	78·04	·621	60·90	46·18	75·5	7·93	376·84	404·5
Carr's Hartley .	7·71	47·8	78·23	·611	63·66	46·86	77·5	8·13	368·53	344·3
Davison's West Hartley . .	7·61	47·7	78·36	·608	64·27	46·96	76·5	7·83	362·99	402·9
North Percy Hartley	7·57	49·1	78·29	·627	56.45	45·62	60·0	7·72	371·68	423·5
Haswells Coal Co.'s Steamboat Wall's-end . . .	7·48	49·5	79·36	·623	60·32	45·25	79·5	7·85	373·66	291·8
Derwentwater's Hartley . .	7·42	50·4	78·79	·639	56.32	44·44	63·5	7·66	373·93	451·1
Original Hartley .	6.82	49·1	77·98	·629	58·81	45·62	80·0	6·98	334·86	428·4
Cowpen & Sidney Hartley . .	6·79	47·9	78·67	·608	64·23	46·76	74·0	7·02	325·24	350·4
Lydney, Forest of Dean . . .	8·52	54·4	80·04	·680	47·02	41·14	55·0	8·98	463·86	487·19
Staveley, Derbyshire	7·26	49·9	79·79	·625	52·90	44·88	88·5	7·46	362·27	466·2
Broomhill . .	7·30	52·5	79·79	·673	45·55	42·67	65·7	7·33	383·25	397·8
Slievardagh (Irish Anthracite).	9·85	62·8	99·57	·630	58·55	35·66	74·0	10·49	618·58	473·2
SCOTCH COALS.										
DalkeithJewelSeam	7·08	49·8	79·67	·625	5·98	49·98	85·7	7·10	352·58	355·2
Dalkeith Coronation Seam .	7·71	51·6	78·61	·657	52·17	43·16	88·2	7·86	398·29	370·1
Wallsend Elgin .	8·46	54·6	78·61	·694	43·78	41·02	64·0	8·67	460·82	435·7
Fordel Splint . .	7·56	55·0	78·61	·699	42·92	40·92	63·0	7·69	415·80	464·9
Grangemouth . .	7·40	54·25	80·48	·674	48·35	40·33	69·7	7·91	401·45	380·40
Wellewood . .	8·24	52·6	79·78	·659	53·57	42·58	80·0	8·39	433·42	438·5
Eglinton . .	7·37	52·0	79·84	·651	51·48	43·07	79·5	7·48	383·24	406.2
Conception Bay, Chill . . .	5·72	..	80·54	..	..	..	..	5·96	..	425·0
PATENT FUELS.										
Warlich's Patent Fuel . . .	10·36	69·05	72·25	·955	4·49	32·44	..	10·60	715·13	457·8
Lyon's Patent Fuel	9·58	61·1	74·73	·817	22·30	36·66	..	9·77	585·33	409·1
Wylam'sPatentFuel	8·92	65·08	68·63	·948	5·45	34·41	..	9·74	580·51	418·9
Bell's Patent Fuel .	8·53	65·3	71·12	·918	8·91	34·30	..	8·65	567·0	549·1

2.—SHOWING THE COMPOSITION OF AVERAGE SAMPLES OF THE COALS.

Locality or Name of Coal.	Specific gravity of Coals.	Carbon.	Hydrogen.	Nitrogen.	Sulphr.	Oxygen	Ash.	Per-centage of Coke left by each Coal.
WELSH COALS.	A.	B.	C.	D.	E.	F.	G.	H.
Craigola	1·30	84·87	3·84	0·41	0·45	7·19	3·24	85·5
Anthracite	1·375	91·44	3·46	0·21	0·79	2·58	1·52	92·9
Oldcastle Fiery vein	1·289	87·68	4·89	1·31	0·09	3·39	2·64	79·8
Ward's Fiery vein	1·344	87·87	3·93	2·02	0·83	included in ash.	7·04	
Binea coal	1·304	88·66	4·63	1·43	0·33	1·03	3·96	81·10
Llangennech	1·312	85·46	4·20	1·07	0·29	2·44	6·54	83 7
Pentrepoth	1·31	88·72	4·50	0·18		3·24	3·36	82·2
Pentrefellin	1·358	85·52	3·72	Trace	0·12	4·55	6·09	85 0
Duffryn	1·326	88·26	4·66	1·45	1·77	0·60	3·26	84·3
Mynydd Newydd	1·31	84·71	5·76	1·56	1·21	3·52	3·24	74·8
Three-quarter Rock vein	1·34	75·15	4·93	1·07	2·85	5·04	10·96	62·5
Cwm Frood Rock vein	1·255	82·25	5·84	1·11	1·22	3·58	6·00	68·8
Cwm Nanty-Gros	1·28	78·36	5·59	1·86	3·01	5·58	5·60	65·6
Resolven	1·32	79·33	4·75	1·38	5·07	included in ash.	9·41	83·9
Pontypool	1·32	80·70	5·66	1·35	2·39	4·38	5·52	64·8
Bedwas	1·32	80·61	6·01	1·44	3·50	1·50	6·94	71·7
Ebbw Vale	1·275	89·78	5·15	2·16	1·02	0·39	1·50	77·5
Porthmawr Rock vein	1·39	74·70	4·79	1·28	0·81	3·60	14·72	63·1
Coleshill	1·29	73·84	5·14	1·47	2·34	8·29	8·92	56·0
Thomas's Merthyr	1·30	90·12	4·33	1·00	0·85	2·02	1·68	86·53
Nixon's Merthyr	1·31	90·27	4·12	0·63	1·30	2·53	1·25	79·11
Hill's, Plymouth Works	1·35	88·49	4·00	0·46	0·84	3·82	2·39	82·25
Aberdare Co.'s Merthyr	1·31	88·28	4·24	1·06	0·91	1·65	3·26	85·83
Gadley nine-feet seam	1·33	86·18	4·31	1·09	0·87	2·21	5·34	86·54
Neath Abbey	1·31	89·04	5·06	1·07	1·60		3·55	61·42
Gadley Four-feet seam	1·32	88·56	4·79	0·88	1·21		4·88	68·23
Llynvi	1·28	87·18	5·06	0·86	1·33	2·53	3·04	72·94
Rock Vawr	1·29	77·98	4·39	0·57	0·96	8·55	7·55	62·50
LANCASHIRE COALS.								
Balcarras Arley	1·26	83·54	5·24	0·98	1·05	5·87	3·32	62·89
Blackley Hurst	1·26	82·01	5·55	1·68	1·43	5·28	4.05	57·84
Blackbrook Little Delf	1·26	82·70	5·55	1·48	1·07	4·89	4·31	58·48
Rushy Park Mine	1·28	77·76	5·23	1·32	1·01	8·99	5 69	56·66
Blackbrook, Rushy Park	1·27	81·16	5·99	1·35	1·62	7·20	2·68	58·10
Johnson and Wirthington's, Rushy Park	1·28	79·50	5·15	1·21	2·71	9·34	2·19	57·52
Laffak, Rushy Park	1·35	80·47	5·72	1·27	1·39	8·33	2·82	56·26
Balcarras Haigh Yard	1·28	82·26	5·47	1·25	1·48	5·64	3·90	66·09
Cannel (Wigan)	1·23	79·23	6·08	1·18	1·43	7·24	4·84	60·33
Balcarras Lindsay	1·26	83·90	5·66	1·40	1·51	5·53	2·00	57·84
Balcarras Five-feet	1·26	74·21	5·03	0·77	2·09	8·09	9·21	55·90
Johnson and Wirthington's (Sir John)	1·31	72·86	4·98	1·07	1·54	8·15	11·40	56·15
NEWCASTLE COALS.								
Andrew's House (Tanfield)	1·26	85·58	5·31	1·26	1·32	4·39	2·14	65·13
Newcastle Hartley	1·29	81·81	5·50	1·28	1·09	2·58	7·14	64·61
Hedley's Hartley	1·34	80·26	5·28	1·16	1·78	3·40	9·12	72·31
Bates West Hartley	1·25	80·61	5·26	1·52	1·85	6·51	4·26	
Buddle's West Hartley	1·33	80·75	5·04	1·46	1·04	7·86	3·85	
Hastings Hartley	1·25	82·24	5·42	1·61	1·35	6·44	2·94	35·60
Carr's Hartley	1·25	79·83	5·11	1·17	0·82	7 86	5·21	60·63
Davison's West Hartley	1·25	83·26	5·31	1·72	1·38	2·50	5·84	59·49
North Percy Hartley	1·25	80·05	5·08	0·98	0·78	9·91	3·22	57·18
Haswell Coal Co.'s Steamboat Wallsend	1·27	83·71	5·30	1·06	1·21	2·79	5·93	61·38
Derwentwater's Hartley	1·36	78·01	4·74	1·84	1·37	10·21	3 73	54·83
Original Hartley	1·25	81·18	5·56	0·72	1·14	8·03	3·07	58·22
Cowpen and Sydney Hartley	1·26	82·20	5·10	1·69	0·71	77·9	2·33	58·59

Locality or Name of Coal.	Specific gravity of Coal.	Carbon.	Hydrogen.	Nitrogen.	Sulphr.	Oxygen	Ash.	Per-centage of coke left by each Coal.
NEWCASTLE COALS.	A.	B.	C.	D.	E.	F.	G.	H.
Park End, Sydney	1·28	73·52	5·69	2·04	2·27	6·48	10·00	57·80
Staveley (Derbyshire)	1·27	79·35	4·84	1·28	0·73	10·96	2·40	57·86
Broom-hill	1·25	81·70	6·17	1·84	2·85	4·37	3·07	59·20
Slievardagh, Irish Anthracite	1·59	80·06	2·30	0·23	6·76	included in ash.	10·80	90·10
SCOTCH COALS.								
Dalkeith Jewel Seam	1·27	74·55	5·14	0·10	0·33	15·51	4·37	49·80
Dalkeith Coronation Seam	1·31	76·94	5·20	Trace	0·38	14·37	3·10	53·50
Wallsend Elgin	1·20	76·09	5·22	1·41	1·53	5·05	10·70	58·45
Fordel Splint	1·25	79·38	5·50	1·13	1·46	3·33	4·00	52·05
Grangemouth	1·29	79·85	5·28	1·35	1·42	6·58	3·52	56·60
Wellewood	1·27	81·36	6·28	1·53	1·57	6·37	2·89	59·15
Eglinton	1·25	80·06	6·50	1·55	1·38	8·05	2·44	54·94
FOREIGN COALS.								
Formosa Island	1·24	78·26	5·70	0·64	0·49	10·95	3·96	
Borneo (Labuan kind)	1·26	64·52	5·74	0·80	1·45	20·75	7·74	
Borneo, 3-feet seam	1·37	54·31	5·03	0·98	1·14	24·22	14·32	
Borneo, 11-feet seam	1·21	70·33	5·41	0·67	1·17	19·19	3·23	
Conception Bay, Chili	1·29	70·55	5·76	0·95	1·98	13·24	7·52	43·63
Sydney, N. S. Wales		82·39	5·22	1·23	0·70	6·32	3·04	
Port Famine		64·18	5·23	0·50	1·03	22·75	6·21	
Chirique		58·98	4·01	0·58	6·14	13·58	36·91	
Laredo Bay		55·67	5·52	0·71	1·14	17·33	16·63	
Sandy Bay, Patagonia, No. 1.		69·25	5·05	0·63	1·13	17·54	13·40	
Ditto ditto, No. 2.		59·63	5·03	0·64	0·93	17·45	15·64	
Talcahnano Bay		70·71	6·44	1·08	0·94	13·95	6·92	
Vancouver's Island		66·93	5·32	1·02	2·20	8·70	15·83	
Colcurra Bay, Chili		78·30	5·50	1·09	1·06	8·37	5·68	
PATENT FUELS.								
Warlich's Patent Fuel	1·15	90·02	5·56	Trace	1·62	included in ash.	2·91	85·10
Lyons ditto ditto	1·13	86·36	4·56	1·06	1·29	2·07	4·66	
Wylam's ditto ditto	1·10	79·91	5·69	1·68	1·25	6·63	4·84	65·80
Well's ditto ditto	1·14	87·86	5·23	0·81	0·71	0·42	4·96	71·70

3.—SHOWING THE AMOUNT OF VARIOUS SUBSTANCES PRODUCED BY THE DESTRUCTIVE DISTILLATION OF CERTAIN COALS.

Name of the Coal.	Coke.	Tar.	Water.	Ammonia.	Carbon. Acid.	Sulph. Hydrogen.	Olefiant Gas and Hydro-Carbon.	Other Gases inflammable.
Graigola	85·50	1·20	3·10	0·17	2·79	Traces	0·23	7·01
Anthracite, from Jones, Aubrey and Co.	92·90	none	2·87	0·20	0·06	0·04	(?)	3·93
Oldcastle Fiery vein	79·80	5·86	3·39	0·35	0·44	0·13	0·27	9·77
Ward's Fiery Vein		1·80	3·01	0·24	1·80	0·21	0·21	
Binea Coal	88·10	2·06	3·58	0·08	1·68	0·09	0·31	4·06
Llangennech	86·69	1·22	4·07	0·06	3·21	0·02	0 43	7·28

TABLE No. XIII.

TABLE OF THE TEMPERATURES AND RELATIVE VOLUMES OF STEAM OF DIFFERENT DENSITIES.

Pressure in pounds per square inch.	Corresponding temperature, Fahrenheit.	Relative Volume of the Steam.	Pressure in pounds per square inch.	Corresponding temperature, Fahrenheit.	Relative Volume of the Steam.
lbs.	degrees.	volume.	lbs.	degrees.	volume.
1	102·9	20868	31	253·6	857
2	126·1	10874	32	255·5	833
3	141·0	7437	33	257·3	·810
4	152·3	5685	34	259·1	788
5	161·4	4617	35	260·9	767
6	169·2	3897	36	262·6	748
7	175·9	3376	37	264·3	729
8	182·0	2983	38	265·9	712
9	187·4	2674	39	267·5	695
10	192·4	2426	40	269·1	679
11	197·0	2221	41	270·6	664
12	201·3	2050	42	272·1	649
13	205·3	1904	43	273·6	635
14	209·1	1778	44	275·0	622
15	212·8	1669	45	276·4	610
16	216·3	1573	46	277·8	598
17	219·6	1488	47	279·2	586
18	222·7	1411	48	280·5	575
19	225·6	1343	49	281·9	564
20	228·5	1281	50	283·2	554
21	231·2	1225	51	284·4	544
22	233·8	1174	52	285·7	534
23	236·3	1127	53	286·9	525
24	238·7	1084	54	288·1	516
25	241·0	1044	55	289·3	508
26	243·3	1007	56	290·5	500
27	245·5	973	57	291·7	492
28	247·6	941	58	292·9	484
29	249·6	911	59	294·2	477
30	251·6	883	60	295·6	470

TABLE No. XIV.—*Mile Table.*

Min.	SECONDS. 0	1	2	3	4	5	6	..	7	8	9	10	11	12	13	14
	MILES PER HOUR.															
3	20·000	19·890	19·780	19·672	19·564	19·460	19·355	..	19·251	19·150	19·047	18·947	18·848	18·750	18·652	18·556
4	15·000	14·938	14·876	14·815	14·754	14·694	14·634	..	14·575	14·516	14·457	14·400	14·342	14·285	14·220	14·173
5	12·000	11·960	11·920	11·880	11·841	11·803	11·764	..	11·726	11·688	11·650	11·613	11·575	11·538	11·501	11·465
6	10·000	9·972	9·944	9·917	9·890	9·863	9·830	..	9·809	9·783	9·756	9·729	9·703	9·677	9·651	9·625
7	8·571	8·551	8·530	8·510	8·490	8·470	8·450	..	8·430	8·413	8·391	8·372	8·352	8·333	8·314	8·295
8	7·500	7·484	7·468	7·453	7·438	7·422	7·407	..	7·392	7·377	7·362	7·346	7·331	7·317	7·302	7·287
9	6·666	6·654	6·642	6·629	6·617	6·605	6·593	..	6·581	6·569	6·557	6·545	6·533	6·521	6·509	6·498
10	6·000	5·990	5·980	5·970	5·960	5·950	5·940	..	5·930	5·921	5·911	5·901	5·891	5·882	5·872	5·863
11	5·454	5·446	5·438	5·429	5·421	5·413	5·405	..	5·397	5·389	5·381	5·373	5·365	5·357	5·349	5·341
12	5·000	4·993	4·986	4·979	4·972	4·965	4·958	..	4·951	4·945	4·938	4·931	4·924	4·918	4·911	4·904
13	4·615	4·609	4·603	4·597	4·591	4·585	4·580	..	4·574	4·568	4·562	4·556	4·551	4·545	4·539	4·534
14	4·285	4·280	4·275	4·270	4·265	4·260	4·255	..	4·250	4·245	4·240	4·235	4·230	4·225	4·220	4·215

Min.	SECONDS. 15	16	17	18	19	20	21	..	22	23	24	25	26	27	28	29
	MILES PER HOUR.															
3	18·461	18·367	18·274	18·181	18·090	18·000	17·910	..	17·823	17·734	17·647	17·560	17·475	17·391	17·307	17·225
4	14·118	14·063	14·008	13·953	13·900	13·846	13·793	..	13·740	13·688	13·636	13·584	13·533	13·483	13·432	13·383
5	11·428	11·392	11·356	11·321	11·285	11·250	11·215	..	11·180	11·145	11·111	11·077	11·043	11·009	10·975	10·942
6	9·600	9·574	9·549	9·524	9·490	9·473	9·448	..	9·424	9·399	9·375	9·350	9·326	9·302	9·278	9·254
7	8·275	8·256	8·238	8·219	8·200	8·181	8·163	..	8·144	8·126	8·108	8·090	8·071	8·059	8·035	8·017
8	7·272	7·258	7·243	7·229	7·214	7·200	7·185	..	7·171	7·157	7·142	7·128	7·114	7·100	7·086	7·072
9	6·486	6·474	6·463	6·451	6·440	6·428	6·417	..	6·405	6·394	6·383	6·371	6·360	6·349	6·338	6·327
10	5·853	5·844	5·834	5·825	5·815	5·806	5·797	..	5·787	5·778	5·769	5·760	5·750	5·741	5·732	5·723
11	5·333	5·325	5·317	5·309	5·301	5·294	5·286	..	5·278	5·270	5·263	5·255	5·247	5·240	5·232	5·224
12	4·897	4·891	4·884	4·878	4·871	4·864	4·858	..	4·851	4·845	4·838	4·832	4·825	4·819	4·812	4·806
13	4·528	4·522	4·516	4·511	4·505	4·500	4·494	..	4·488	4·483	4·477	4·472	4·466	4·460	4·455	4·449
14	4·211	4·206	4·201	4·196	4·191	4·186	4·181	..	4·176	5·171	4·166	4·161	4·157	4·152	4·147	4·142

TABLE No. XIV.—*Mile Table—continued.*

Min.	SECONDS. 30	31	32	33	34	35	36	..	37	38	39	40	41	42	43	44
	MILES PER HOUR.															
3	17·143	17·061	16·981	16·901	16·822	16·744	16·667	..	16·590	16·514	16·438	16·363	16·289	16·216	16·143	16·071
4	13·333	13·284	13·235	13·186	13·138	13·091	13·043	..	12·996	12·950	12·903	12·857	12·811	12·766	12·721	12·676
5	10·909	10·876	10·843	10·810	10·778	10·746	10·714	..	10·682	10·651	10·619	10·588	10·557	10·526	10·495	10·465
6	9·230	9·207	9·183	9·160	9·137	9·113	9·090	..	9·068	9·045	9·022	9·000	8·977	8·955	8·933	8·911
7	8·000	7·982	7·964	7·947	7·929	7·912	7·895	..	7·877	7·860	7·843	7·826	7·809	7·792	7·779	7·758
8	7·059	7·045	7·031	7·017	7·004	6·990	6·977	..	6·963	6·950	6·936	6·923	6·905	6·896	6·883	6·870
9	6·315	6·304	6·293	6·282	6·271	6·260	6·250	..	6·239	6·228	6·217	6·207	6·196	6·185	6·174	6·164
10	5·714	5·705	5·696	5·687	5·678	5·669	5·660	..	5·651	5·642	5·633	5·625	5·616	5·607	5·598	5·590
11	5·217	5·210	5·202	5·195	5·187	5·179	5·172	..	5·164	5·157	5·150	5·142	5·135	5·128	5·121	5·114
12	4·800	4·793	4·787	4·780	4·774	4·768	4·761	..	4·755	4·749	4·743	4·738	4·730	4·724	4·718	4·712
13	4·444	4·438	4·433	4·428	4·422	4·417	4·411	..	4·406	4·400	4·395	4·390	4·384	4·379	4·374	4·368
14	4·137	4·133	4·128	4·123	4·118	4·114	4.110	..	4·105	4·100	4·095	4·090	4·086	4·081	4·077	4·072

Min.	SECONDS. 45	46	47	48	49	50	51	..	52	53	54	55	56	57	58	59
	MILES PER HOUR.															
3	16·000	15·929	15·859	15·789	15·721	15·652	15·584	..	15·517	15·450	15·384	15·319	15·254	15·190	15·126	15·062
4	12·631	12·587	12·543	12·500	12·456	12·413	12·371	..	12·329	12·287	12·245	12·203	12·162	12·121	12·080	12·040
5	10·434	10·404	10·375	10·345	10·315	10·286	10·256	..	10·227	10·198	10·169	10·140	10·112	10·084	10·055	10·027
6	8·889	8·867	8·845	8·823	8·801	8·780	8·759	..	8·737	8·716	8·695	8·675	8·651	8·633	8·612	8·591
7	7·741	7·725	7·708	7·692	7·675	7·659	7·643	..	7·627	7·610	7·595	7·579	7·563	7·547	7·531	7·515
8	6·857	6·844	6·831	6·818	6·805	6·792	6·779	..	6·766	6·754	6·741	6·729	6·716	6·704	6·691	6·679
9	6·153	6·143	6·132	6·122	6·112	6·101	6·091	..	6·081	6·070	6·060	6·050	6·040	6·030	6·020	6·010
10	5·581	5·572	5·564	5·555	5·547	5·538	5·530	..	5·521	5·513	5·504	5·496	5·487	5·479	5·471	5·463
11	5·106	5·099	5·091	5·084	5·077	5·070	5·063	..	5·056	5·049	5·042	5·035	5·028	5·020	5·013	5·006
12	4·706	4·700	4·693	4·687	4·681	4·675	4·669	..	4·663	4·657	4·651	4·645	4·639	4·633	4·627	4·621
13	4·363	4·358	4·353	4·347	4·342	4·337	4·332	..	4·326	4·321	4·316	4·311	4·306	4·301	4·295	4·290
14	4·067	4·063	4·058	4·054	4·049	4·044	4·040	..	4·035	4·031	4·026	4·022	4·017	4·013	4·008	4·004

GLOSSARY

OF

TERMS CONNECTED WITH MARINE ENGINES AND BOILERS.

(*WITH FRENCH TRANSLATIONS.*)

Air-casing, of thin sheet iron, (la chemise,) surrounds the bottom of the chimney, to prevent the radiation of heat to the deck.

Air-pipe, a small copper pipe leading from the top of the hot-well through the ship's side, for the discharge of the air and uncondensed vapour pumped by the air-pump.

Air-pump, (la pompe à air,) is required to maintain the vacuum in the condenser by withdrawing the condensing water, air, and uncondensed vapour.

Air-tubes, are small wrought-iron tubes hung in the coal-boxes from the deck, and filled with water, for the purpose of ascertaining the temperature of the coals by a thermometer, as a precaution against spontaneous combustion.

Angle-iron, (cornière).

Annular-piston, is one made in the form of a ring encircling an inner cylinder which is enclosed within the external one. This arrangement is sometimes adopted to gain length of connecting-rod, by causing it to descend within the inner cylinder.

Anvil, (masse).

Ash-pits, (cendriers,) underneath the fire-bars of the furnaces, where the ashes collect.

Atmospheric or *single-acting engine* (machine à vapeur atmosphérique,) is a condensing engine in which the pressure of the steam acts during the up-stroke only, the return stroke being performed by the pressure of the atmosphere acting against a vacuum.

Auxiliary or *feeding engine*, (machine alimentaire,) fitted to supply tubular boilers with feed-water when the large engines are not working, and the ordinary feed-pumps are therefore inactive.

Axle, (tourillon).

Babbit's patent soft-metal bushes, are formed of an alloy of 1 lb. copper, 50 lbs. tin, 5 lbs. regulus of antimony.

Back-balance of eccentric, (contrepoid d'excentrique,) is fixed to the back of the eccentric pulley for the purpose of balancing its weight on the shaft.

Back-balance of slide valves, is the weight fixed at the extremity of the valve-lever for balancing the weight of the slides.

Back-lash, is the term given to the jar which ensues when one portion of the machinery which receives motion from another (but without being always in actual contact) has its velocity so increased from some extraneous cause, that it falls back, with a sudden blow, upon the part from which it ought to derive its motion.

Back-links, the links in a parallel motion which connect the air-pump rod to the beam.

Ballast, (sable).

Banking-up the fires, raking them to the bridge of the furnace, and then smothering them with cinders and small coal, the draught being at the same time checked. By this means the fires are kept in a state of languid combustion, but are ready to burn up briskly again when steam is wanted at short notice, the red-hot mass being then broken up, raked forward, and the draught re-admitted.

Barometer or *vacuum-gauge*, (baromètre,) is fitted to the condenser of an engine to show the vacuum. It resembles the common weather-barometer, except that the top of the tube is in communication with the condenser.

Barrel of a pump, (corps d'une pompe).

Base-plate, see *Sole-plate*.

Beam or *side-lever engines*, (machines à balanciers,) are those in which the motion of the piston is communicated to the crank through rocking beams or levers at the sides.

Beams of a vessel, (travers).

Bearers, (supports,) are the cross bars in the furnaces supporting the ends of the fire-bars.

Bear, is a small apparatus for punching holes by hand.

Bearing neck or *journal* of a shaft, (coussinet d'un arbre,) is the part which revolves within the pedestal-brasses, and supports the weight or strain.

Bedding of a boiler, (lit d'une chaudière,) is the seat on which it rests.

Bilge-pumps, (pompes d'épuisement de cale,) worked by the engine, to clear the water from the bilge of the ship.

Blowing-off, (vidange de chaudière,) the process of ejecting the super-salted water from the boiler in order to prevent the deposition of scale or salt.

Blow-off cocks, and *pipes*, are those through which the brine is ejected.

Blowing-through, (purger d'air,) is the process of clearing the engine of air by blowing steam through the cylinder, valves, and condenser, before starting.

Blow-through valve, (soupape à purger d'air,) is fitted between the valve-casing and the condenser for the temporary passage of the steam used in blowing through.

Boiler, low pressure, high pressure, (chaudière à basse pression, à haute pression).

Bolt; bolted, (boulon; boulonné).

Boss, (renflement,) is a centre or swelling of any kind in which a hole or eye is bored.

Box-keys, are the upright keys used for turning the nuts of large bolts, or where the common spanner cannot be applied.

Bracket, pedestal, or *plummer-block*, the fixed support for the bearing of a shaft in motion, formed so that it can be fixed vertically to the frame of an engine or the side of a beam, etc.

Brass, (bronze,) an alloy of copper, tin, and zinc, in different proportions. Tough brass, for engine-work, is formed of 10 lbs. copper, 1½ lb. tin, and 1½ lb. zinc. Brass for heavy bearings, of 1 lb. copper, 2½ oz. tin, ½ oz. zinc.

Break or *brake*, (frein).

Bridge of a boiler, is the barrier of fire-bricks or iron plates containing water, thrown across the furnace at the extreme end of the

fire-bars, to prevent the fuel being carried into the flues, and to quicken the draught by contracting the area.

Brine-pumps, (pompes de saumure,) are worked by the engines to withdraw the super-salted water from the boilers methodically, instead of by periodical blowing-off.

Bulkheads, (cloisons).

Bush, is a lining of brass, steel, or other metal, fitted in an eye or bearing, either to diminish friction or prevent rapid wear.

Callipers, are compasses with round legs, used for taking the diameter or thickness of circular or flat inside work about an engine. *Inside callipers*, are used for measuring the internal diameter of a brass or hole of any kind.

Cam, for expansion, is a disc of cast iron having the periphery cut in an irregular figure, for giving the proper motion to the expansion valve. It is graduated in steps, so as to suit the different degrees of expansion.

Carriage by sea, (transportation); *by land*, (montage).

Cast, (coulé).

Cast-iron, (fonte).

Cataract, is a contrivance introduced into marine engines for softening the fall of the expansion valves when these are made upon the Cornish principle. It consists of a little brass cylinder filled with water or oil, and fitted with a solid piston connected by a cross-head with the valve spindle. The fall of the valve is checked and regulated by the escape of the water or oil through a small hole bored for that purpose in the side of the cylinder, the piston of the cataract descending according as the liquid is forced out from before it by the pressure due to the weight of the expansion-valve.

Cement, (ciment, mastic).

Centre-boss, of the paddle-wheels, (renflement central des roues à aubes).

Chimney, (cheminée).

Chisel, (ciseau, burin).

Clack-valve, (clapet,) a flat valve with a hinge-joint.

Clearance of the piston, is the small space left between the piston and the top and bottom of the cylinder at the end of each stroke.

Clinkers, (scories,) are the incombustible matter left on the fire-bars during the combustion of the coal.

Clinker-bar, (traverse de cendrier,) is fixed across the top of the ash-pit to support the *slice* used for clearing the interstices of the bars.

Clothing (enveloppe) the steam-pipes, boilers, etc., means covering them with felt and other non-conducting materials, to prevent the radiation of heat.

Coals; coal bunkers, (les houilles, charbon; soutes à charbon).

Coal-trimmer, a man whose duty it is to work within the coal-boxes, and bring the coals to the doors at the boiler front, as they continue to be consumed.

Cock, (robinet).

Cogged wheels, (roues dentées,) are those fitted with wooden teeth or *cogs*, for the purpose of lessening friction and giving smoothness of action.

Cold-chisel, (ciseau à froid,) a chisel properly tempered for cutting cold iron.

Collar of a shaft, (collier,) is the projecting rim on each side of the neck or bearing, to confine it sideways during its revolution.

Common steam, in contradistinction to *super-heated* steam, is steam in contact with the water from which it was generated.

Condenser, (condensateur,) is the cast-iron box in which the process of condensation takes place.

Condensing engine, (machine à condensation,) is one in which the steam is condensed after leaving

the cylinder for the purpose of gaining the effect of the atmospheric pressure.

Connecting-rod, (bielle de la manivelle,) in a direct-acting engine, communicates the motion directly from the head of the piston-rod to the crank: in a side-lever engine, from the cross-tail to the crank.

Consumption of fuel, (consommation de combustible).

Counter, (compteur,) a little instrument employed for registering the strokes of an engine.

Coupling of a shaft, (accouplement,) is the mode of connecting together two or more lengths of a revolving shaft, by shaping the ends into flat surfaces or bearings, which are held together by a strong iron bush or *coupling-box*.

Cover or *lap of the slide-valve on the steam side*, (recouvrement des tiroirs,) is the space which it advances beyond the opening of the steam-port after it has closed it, and is given for the purpose of causing the engine to work expansively, by cutting off the admission of steam before the end of the stroke.

Cover or *lap on the exhausting side* of the piston, causes the passage to the condenser to be closed before the end of the stroke, the piston being then said to be *cushioned* by the elasticity of the confined vapour upon which it descends.

Crank; cranked, (manivelle, coude; coudé).

Crew of a vessel, (l'équipage d'un vaisseau).

Cross-head, (traverse, tête croissée,) in a side-lever engine, crosses the head of the piston-rod, and communicates the motion to the side-rods.

Cross-tail, in a side-lever engine, takes the motion from the side-rods and communicates it to the connecting-rod.

Cup-valve, resembles a conical valve, but has no spindle, being turned in the form of a cup or portion of a sphere.

Cushioning the piston, means that a small portion of steam is shut up between the piston and the cylinder top and bottom at the end of each stroke, which acts as a spring, to soften the shock, and to give the piston a start forward after the centre is turned. This effect is produced by the lap of the slide-valve on the exhausting side.

Cutter, (clavette,) is the wedge-key used, in combination with the *gib*, (contre-clavette,) for tightening the strap and brasses of a bearing, as the latter wear by friction.

Cutting-off the steam for expansion, (la détente).

Cylinder-cover, (couvercle de cylindre).

Dampers, (les registres,) are iron plates, fitted by a hinge or otherwise, across the fronts of the ash-pits and the bottom of the chimney, for the purpose of regulating the draught. They are capable of being adjusted by hand to any desired area.

Dead fires, when they burn sluggishly.

Dead-plate, a flat iron plate frequently fitted before the bars of a furnace for the purpose of coking bituminous coal upon before it is thrown back upon the fire.

Dead-water, (eau morte,) is the current following in the wake of a ship and partaking of her motion.

Deck, (pont).

Depth of a vessel, (hauteur d'un vaisseau).

Diagram of indicator, (courbe d'indicateur,) the figure traced by the pencil, from which the pressure is calculated.

Dip of the wheels, (immersion des roues,) the depth of water over the top of the vertical board.

Direct-acting engines, (machines à

action directe,) are those in which the motion of a piston is communicated *directly* from the head of the piston-rod to the crank through the connecting-rod, without the intervention of side-levers.

Discharge, delivery, or *waste-water pipe and valve*, (tuyau et soupape de décharge ou de sortie,) are those through which the heated condensing water and vapour are discharged into the sea by the air-pump.

Disengaging or *disconnecting the paddles or screw* from the engines, by suitable machinery, permits them and their shaft to revolve freely in the brasses by the re-action of the water, by which means the speed of the ship when under canvas is not so much affected as if they were dragged through the water.

Displacement, (déplacement,) of a vessel, is the weight of water which she *displaces*, being equal to her own weight.

Donkey or *auxiliary engine*, (machine alimentaire,) is used for feeding the boilers while the large engines are at rest.

Double-acting engine, (machine à double action,) is one in which the steam acts against a vacuum on each side of the piston alternately, as in the ordinary marine engine.

Double-acting pump, is one which lifts and forces water alternately, by means of a solid piston or plunger and an entrance and exit valve communicating with each side, (as the feed and bilge pumps of a marine engine).

Double-cylinder engine, as patented by Messrs. Maudslay, has two cylinders, between which the lower end of the connecting-rod descends, its motion being communicated from the piston-rod by a bent cross-head working in grooves between the cylinders.

Draught of the chimney, (tirage).

Draught of water, (tirant d'eau).

Drift, (repoussoir,) is a round piece of steel, made slightly tapering, and used for enlarging a hole in a metal plate by being driven through it.

Drip-pipe, is a small copper pipe leading from the waste steam pipe inside, to carry off the condensed steam and other hot water which may be blown into the "trap" at the top.

Driving wheel, (roue motrice,) in the gearing of a screw vessel, is that which communicates motion to the small wheel or *pinion*.

Drum, is a hollow cylinder fixed on a shaft for driving another shaft by a band.

Dynamometer, (dynamomètre,) is an instrument for indicating the thrust of the screw-propeller by means or springs and levers.

Eccentric, (l'excentrique,) is the arrangement usually adopted for giving the proper stroke to the valves. It consists of the *eccentric pulley*, of cast iron, which is loose on the intermediate shaft, and the *hoop*, of wrought iron lined with brass, which encircles the pulley, and gives motion to the *eccentric rod*. The *eccentric stops* or *snugs* are two little projections fixed on the intermediate shaft for the purpose of carrying round the eccentric pulley, according as it is wanted to go ahead or astern, the pulley itself being free to revolve backwards or forwards between the two stops. The weight of the pulley is balanced on the shaft by the back-balance cast on it.

Eduction or *exhaust passages* (tuyaux de sortie ou d'émission), through which the steam passes from the valves to the condenser.

Effective diameter of a paddle-wheel is generally reckoned at one third of the breadth of the boards from each extremity of the diameter.

Effective heating surface, (puissance calorifique), in a boiler is that

which is considered of value in evaporating the water. The bottom surface of the flues and furnaces, and one-third of the whole surface of the tubes in tubular boilers, are usually rejected as *ineffective.*

Engine beams cross through the engine room at the height of the entablatures, to steady them, and receive part of the thrust of the paddle-wheels.

Engine bearers or sleepers, (poutres de fondement,) are the longitudinal keelsons through which the foundation-plate is bolted.

Engineer, engine tenter, (machiniste, mechanicien).

Entablature, (entablement,) is the strong iron frame supporting the paddle-shaft. It usually receives additional stiffness from being confined between two beams of timber, called the *entablature* or *engine beams.*

Equilibrium, Cornish, or *double-beat valves,* are frequently used in marine engines as expansion valves. Their peculiarity consists in their being pressed by the steam equally in all directions, so that they rise with a very slight force, exposing at the same time a large area of steam with a very small rise of the valve.

Escape or *priming valves,* (soupapes d'échappement,) are loaded valves fitted to the top and bottom of the cylinder, for the escape of the condensed steam, or of water carried mechanically from the boilers with the steam.

Escape-valves are also fitted to the feed pipes as a means of exit for the surplus water not used by the boilers.

Expansion gear, (l'encliquetage pour l'expansion,) is fitted to marine engines, independently of the cylinder valves, for the purpose of cutting off the steam at different portions of the stroke, according as it is wished to economize fuel more or less. It generally consists of a graduated *cam* on the paddle-shaft, against which a *roller* presses and communicates the movement peculiar to the irregular surface of the cam, through a series of rods and levers, to the *expansion-valve,* situated between the throttle-valve and the slides.

Expansion or *Fawcett joint* is a stuffing-box joint used when a straight metal pipe, (as the steam pipe,) which is exposed to considerable variations of temperature, has no *elbow* or curve in its length, to enable it to expand without injury. In such a case the pipe is divided into two lengths, which are united by a steam-tight joint accurately bored and turned, so as to allow the one pipe to slip within the other, when they lengthen by expansion.

Experiment, (expérience).

Eye of a crank, etc., (encoche, œil,) is a hole bored to receive a shaft or pin.

Fawcett joint, see *Expansion joint.*

Feathering paddle-wheels, (roues à aubes mobiles,) are those in which the requisite machinery is provided for *feathering the boards,* or causing them to enter and leave the water in a perpendicular position. By this means the board leaves the water without lifting it, and the effect of the wheel is somewhat increased.

Feeding apparatus, (l'appareil alimentaire,) for a marine boiler, consists of the *feed pump, feed pipe* passing through the *refrigerator, feed cock* on the boiler, *escape valve* for the surplus water, and *water gauges* to show the level in the boiler.

Feeding engine, see *Auxiliary engine.*

Ferules (viroles) are rings of iron or brass frequently used for fastening the tubes of a tubular boiler in the tube plate.

Files, (limes).

Fire bars, (barres du foyer).

Fire grate, (grille du foyer).

Fire hose, are made adjustible to the discharge pipes from the bilge-pumps, from the auxiliary engine, (where fitted,) and from the hand pump in engine room.

Fire men or stokers, (chauffeurs,) the men who work the fires.

Firing-up, urging the fires, to make them form as much steam as possible.

Flange, (rebord).

Float boards or *paddle boards*, (les aubes).

Flues, (conduits).

Foot-valve, (clapet de fond,) is situated between the bottom of the condenser and the air-pump, opening towards the latter.

Forcing pumps, (pompes foulantes).

Fork, (fourche).

Fork-head, (tête fourchée,) the double head of a rod which divides in order to form a connection by means of a pin.

Foundation or base plate, (plaque du fond,) see *Sole-plate*.

Fox key, is a key with a thin wedge of steel driven into the end, to prevent its working back.

Frame of the engine, (châssis, cadre).

Frames of a vessel, (membrures d'un vaisseau).

Friction, (frottement).

Fuel, (combustible).

Fulcrum, (support, palier, crapaudine).

Furnace, (le foyer, fourneau).

Fusible plugs, (bondelles fusibles,) are sometimes fitted in boilers, being expected to melt by the high temperature of the confined steam, and thus allow it to escape in case of its attaining a dangerous pressure from the safety valve not acting.

Gasket, (garniture d'étoupe,) is the hemp packing, formed of soft cord plaited, which is used for making steam-tight joints.

Gauge cocks, (robinets d'épreuve,) of brass, attached to the front of the boiler, for indicating the level of the water.

Gauge, steam or mercurial, (manomètre de verre, mercurial,) is a siphon tube half filled with mercury, usually employed for showing the pressure of low steam. When a marine boiler uses steam of high tension, a spiral spring is employed.

Gib (contre-clavette), is the fixed iron wedge used, in conjunction with the *cutter* or driving-wedge (clavette), for tightening the straps and brasses of the different bearings.

Gland, (boîte à étoupes,) is the cupped collar (lined with brass,) which encircles the piston and air-pump rod, etc., where it passes through the cover, being for the purpose of holding oil or tallow for lubricating, and for compressing the packing of the stuffing-box upon which it is screwed down.

Glass water gauges, (indicateurs du niveau de l'eau,) attached to the fronts of the boilers for showing the level of the water.

Governor, (régulateur,) in screw engines, is an apparatus by which the steam is shut off from the cylinders (when the speed of the engine becomes too great), by the divergence of two balls from the centrifugal force, according as their velocity is increased.

Grease cock, (robinet à graisse,) on the cylinder cover, for lubricating the piston with melted tallow, without permitting the escape of steam or the entrance of air.

Groove, (trou, entaille).

Guards (gardes,) for the bolts of an engine, are light frames of brass or iron, into which the nuts of the bolts fit, to prevent their working loose by unscrewing.

Gudgeon, (goujon,) is any short pin or shaft used as a bearing for a moving portion of the machinery.

Guides, (glissoirs,) are smooth sur-

faces between which the head of a piston-rod, etc., slides, to preserve its parallelism; the sliding block attached to the cross-head being called the *Guide block*.

Gun metal, (bronze,) an alloy of brass very generally employed in engine work. It is formed by melting together 1 lb. of tin, 1 lb. zinc, and 8 lbs. copper.

Hall's condensers, a method of surface condensation in which the steam is condensed by passing through a large number of small tubes immersed in cold water.

Hammers (marteaux,) of three sizes, the largest being called *sledge hammer*; the next, *flogging hammer*; and the smallest, *hand hammer*.

Handle, (manette).

Hand pump, (pompe à bras,) is fitted in the engine room for filling and feeding the boilers by hand, for washing the decks, extinguishing fire, etc. It is always made capable of being attached to the engines when they are working.

Heat; heating power, (chaleur; puissance calorifique).

Helm; helmsman, (timon; timonier).

Hemp, (étoupe).

High-pressure, or more correctly, *non-condensing engines*, (machines à haute pression,) are those which work simply by the excess of the pressure of the steam above that of the atmosphere. Condensing engines, although sometimes using "high-pressure" steam, are never called high-pressure engines.

High pressure steam, (vapeur à haute pression,) is a vague expression denoting steam of a tension above 15 or 20 lbs. pressure above the atmosphere.

Holding-down bolts, (boulons de carène,) are the strong screw-bolts employed to fasten the foundation plate of the engines to the ship's bottom.

Horse-power, nominal, (puissance en chevaux, force de cheval,) is assumed equal to 33,000 lbs. raised one foot high in one minute.

Hot-well, (reservoir à eau chaude, la citerne,) is the reservoir for the water pumped out of the condenser by the air-pump.

Hugging, is the expression used when one vessel is running so close in the wake of another as to be influenced by the current of dead-water following her, in which case the two may continue to keep close together, although the vessel running behind may be, perhaps, a mile an hour slower than the other.

Hull or shell of a boat, (coque d'un bateau).

Incrustation or *scale*, (sédiment,) is the hard coating of salt, lime, and other mineral substances which collect on the inner surface of the plates of a boiler which is not regularly and sufficiently "blown off."

Index of a spring balance, (curseur).

Indicator, (indicateur,) is the little instrument employed for ascertaining the real power, as well as the state of efficiency of the internal parts, of a steam engine, by indicating the actual pressure in the cylinder during each stroke, and the time and manner in which the steam is admitted and shut out by the valves.

Injection, (injection,) is the process of admitting a jet of cold water from the sea into the condenser, to condense the steam as rapidly as possible.

Inside bearings of paddle shaft, (upon a bracket bolted to the ship's side,) are employed when the wheels are "overhung."

Intermediate shaft, is the strong shaft crossing the centre line of the vessel and connecting the paddle shafts of the two engines.

Iron-filings, (limaille).

Joints, (jointures,) articulations.

Journal, (coussinet,) is the neck or bearing part of a shaft, upon which it turns, and by which it is supported.

Junk ring, is a metallic ring confining the hemp packing of the piston (when such is employed), and made capable of being screwed down to compress it.

Keelsons, (carlingues).

Key, (clef,) a wedge piece of iron used for tightening the brasses of a bearing, etc.

Kingston's valves, are conical valves with a screwed spindle, and are very generally used for closing the orifices of the injection and blow-off pipes where they pass through the ship's side.

Knees of iron, (équerres en fer).

Laggings for the cylinder, etc., are the thin staves of wood employed in "clothing," to stop the radiation of heat and consequent condensation of steam.

Lap of the slide valve, see *Cover*.

Larboard engine, (machine de bâbord,) that on the left-hand side of the vessel when looking towards the bow.

Latent heat, (chaleur latente,) is that portion of heat which is absorbed by gases and liquids, in a latent or insensible state, during their transition from a denser to a rarer form; as when water at 212° changes into steam at 212°, and when ice at 32° changes into water at 32°.

Lead of the slide valve, (avance du tiroir,) is the small space which the valve opens to steam at the end of each stroke, upon the opposite side of the piston. It tends to check the velocity of the piston at the end of the stroke, and allows of the valve being open and ready to admit a larger supply of steam the instant the motion of the piston is reversed.

Lead of the crank, (avance de la manivelle). It is usual in direct-acting, and generally in all unbalanced engines, to give what is called *lead* to one of the cranks; which implies that the crank of the one engine is set a little in advance of the right angle to the other; namely, at 100° or 110° in place of 90. This assists in rendering the motion of the piston more uniform, by moderating its velocity at the end of the stroke.

Leather, (cuir).

Length of stroke, (longueur du coup, ou de la course).

Level, (niveau).

Lever, (levier).

Lighter or *barge*, (gabarre).

Links, are short connecting pieces, with a bearing in each end, for transmitting motion from one rod or lever to another.

Link motion, is an ingenious arrangement for working the slides, by which means the travel or stroke of the valve may be varied at pleasure, and expansion given without a separate expansion valve being required. It also affords great facilities for stopping and reversing the engines.

Log, engine-room, a tabulated summary of the performance of the engines and boilers, and of the consumption of coals, tallow, oil, and other engineers' stores.

Lubricators, (godets, ou boîtes à huile,) are the larger description of oil-cups for holding oil and distributing it to the working parts of the engines.

Main centre, (goujon central,) in side-lever engines, is the strong shaft upon which the side levers vibrate.

Man-hole, (trou d'homme,) is a hole in a boiler or tank, fitted with a steam-tight cover, through which a man may enter for the purpose of cleaning and examining the interior.

Metallic packing, for the piston, is

composed of a ring or several rings of iron or other metal, sometimes cast so as to possess elasticity in themselves, or sometimes cut into segments and pressed against the interior of the cylinders by springs, so as to form a steam-tight contact.

Mètre, equals 39·3702 English inches.

Mile, Geographical or *Nautical*, or *knot*, contains 6082·66 feet.

Mile, British Statute, contains 5280 feet, 1760 yards, or 1609 mètres.

Mile-post, (borne milliaire).

Mitre-wheel, (roue à onglet,) has its teeth set at an angle of 45° with the spindle, so as to transmit the motion to another mitre-wheel and shaft at right angles with it.

Morgan's feathering paddle-wheel, see *Feathering paddle-wheels*.

Morticed, (assemblé à mortaise).

Mud hole, (orifice de nettoiement,) fitted with steam and water-tight doors, through which the deposit may be removed from the boilers.

Muntz's metal, used for bearings, etc., is formed of 2 parts of zinc, 3 parts copper. (Hard bearings.)

Nave of a wheel, (moyen).

Neck of a shaft, (coussinet d'un arbre,) is the *journal* or *bearing* on which it turns and is supported.

Non-condensing or *high-pressure engines*, (machines à haute pression,) are those in which the principle of condensation is not applied, the motive power being due solely to the excess of the pressure of the steam above that of the atmosphere.

Notch, (encoche).

Nut, (écrou).

Oil-cups or *lubricators*, (boîtes à huile,) are fitted to the several bearings and rubbing surfaces of the engine for the purpose of lubricating them, to diminish friction.

Oscillating engines, (machines aux cylindres oscillants,) are those in which the cylinders oscillate upon hollow axes or *trunnions*, through which the steam enters the valve casing. By this arrangement, the parallel motion and connecting-rod are dispensed with, the head of the piston-rod being attached directly to the crank-pin.

Outside bearings to paddle-shaft, when the shaft runs through to a bearing on the spring beams.

Overhung paddle-wheels, when the shaft does not run through to a bearing on the spring beams, but is supported by a bracket from the ship's side.

Packing for the piston, slide-valves, etc., (garniture,) is employed to render them steam-tight, and is formed sometimes of rings of iron or other metal pressed outwards by springs (when it is called metallic packing); sometimes by hemp confined by a "junk ring," and compressed by screws (called hemp packing); and sometimes by rings of vulcanized india rubber and other elastic material.

Paddle-wheels; paddle-boxes, (roues à aubes; tambours).

Paddle boards or *float boards*, (les aubes); *paddle-arms*, (les raies des roues).

Parallel motion, (le parallélogramme,) is the name given to the combination of jointed rods usually employed in side-lever engines, and others, for preserving the parallelism of the piston-rod.

Pedestal or *plummer block*, (support,) is the support for a shaft in motion, holding the brasses on which it turns.

Pet cock or *test cock*, (robinet d'essai,) is the name given to a little cock sometimes fitted at the top and bottom of the cylinder, to allow the escape of water from above and below the piston, independently of the escape valves fitted for that purpose. They are kept open until the engines are

fairly under weigh, and are then shut.

Pin, (happe, boulon).

Pitch of a screw, (pars d'un hélice,) is the distance between the threads, or the distance which the screw advances during each revolution when working in a solid.

Pitch circles, are the circles of contact of two or more toothed wheels working in combination.

Pitching of a vessel, (plongement).

Plates, (thin,) (lames, tôles).

Plug, (bouchon).

Plummer block, see *Pedestal*.

Plunger, (plongeur,) a solid piston without valves, used in the feed and bilge pumps, etc.

Ports of the cylinder, (lumières de cylindre,) are the short steam passages leading from the top and bottom of the cylinder to the slide-valve casing.

Priming or *foaming* of the boilers implies, that the water boils over into the steam pipes which lead to the engines, and is caused by the water being dirty, or there being a deficiency of steam-room in the top of the boilers.

Priming valves, see *Escape valves*.

Radius of curvature, (rayon de courbe).

Radius rods or *bars*, (la bride du parallélogramme,) are the guiding rods in a parallel motion jointed to the connecting links to counteract the vibratory motion communicated by the side levers.

Reciprocating, (alternatif).

Reefing the paddles implies disconnecting the float-boards from the paddle-arms, and bolting them again nearer the centre of the wheel, to diminish the dip when the vessel is deep. This is sometimes done by machinery, in what are called *reefing paddle-wheels*.

Refrigerator, is a vessel containing a number of copper tubes, through which the hot brine passes after being ejected from the boiler by the brine-pump. The feed water is at the same time passed through the vessel surrounding the tubes, and has its temperature thus raised by the waste heat of the brine before entering the boiler.

Reverse or *vacuum valves*, (soupapes de sûreté intérieurs,) are small loaded valves opening inwards, and fitted to the boiler to admit air when a vacuum is formed by the condensation of the steam inside, or when the pressure of the steam falls to a few pounds below the pressure of the atmosphere.

Reversing gear, (leviers de renversement,) is the apparatus provided for reversing the motion of the engine by changing the time of action of the slide-valve. This is done by bringing the eccentric *behind*, in place of *in advance of*, the crank.

Ribs, (tirants).

Rocking shaft, the shaft, with levers, frequently used for working the slide-valves, the notch of the eccentric rod dropping into a stud fixed in one of the levers, and the links of the slide-valve spindle being attached to the opposite lever on the same shaft.

Rubbing part, (partie frottante).

Rudder, (gouvernail).

Rust joints, made by spreading over the surfaces to be united a mixture of one ounce of sal-ammoniac to one pound of cast-iron borings.

Safety valves, (soupapes de sûreté,) are fitted to the boilers for the escape of the steam, before it attains a dangerous pressure.

Salinometer, (salinomètre,) is an instrument for measuring the quantity of salt contained in solution in the water of the boiler, by indicating either the specific gravity or the temperature at which it boils.

Scale, (sédiment, incrustation,) is the hard crust of salt, lime, etc., which collects upon the interior surface

of the plates of a boiler when proper attention is not paid to "blowing off." The hammers used for loosening and removing the scale are called *scaling hammers.*

Screw; screwed, (vis; vissé).

Screw bolts, (boulons en vis, boulons taraudés).

Seat of the valve, (siége de la soupape).

Sediment collectors, or *scale pans,* are shallow vessels which are sometimes fixed in boilers about the level of the water, for collecting the particles of sediment which are buoyed up to the surface by bubbles of steam, and which would otherwise settle at the bottom of the boiler.

Sensible heat, in opposition to *latent heat,* is free caloric, which is sensible to, or whose presence is indicated by the thermometer.

Shaft, (arbre).

Sheet iron, (tôle, fer en feuilles).

Shovel, (pelle).

Shrouds for the funnel, are the supporting chains from the deck.

Side-levers, in side-lever engines, (balanciers,) transmit the motion of the piston-rod from the side-rods to the cross-tail of the connecting rod.

Sleepers, or *engine bearers,* (traverses).

Slice, (fourgon, tisonnier,) is the instrument used for clearing the air spaces between the bars of a furnace, when they become choked with *clinkers.*

Slide-valves, (tiroirs, soupapes à tiroir,) are much used for the cylinder steam valves of marine engines. The two kinds most commonly found are called "long D" and "short D" valves, from the form of their cross section; the distinction being, that in the first case the steam enters round the outside of the valve, and exhausts through it, while, in the second, the exhaust takes place alternately from the top and bottom of each of the two short slides, which are strongly joined together by vertical rods.

Slide-casing, or *jacket,* (boîte des tiroirs,) is the cast-iron box within which the slide-valves work.

Slip of the paddle-wheel or screw, is the amount which each *slips back* in its progress through the water, in consequence of the imperfect resistance offered by the fluid, and is therefore equal to the difference between the rate of the wheel or screw and that of the vessel.

Smith, (forgeron).

Smoke box, (boîte à fumée,) is the space in a tubular boiler between the ends of the tubes and the front or back of the boiler. It is fitted with doors, which remove for the purpose of cleaning the tubes with *tube brushes,* and removing ashes and soot.

Smoke-burning apparatus is sometimes fitted to boilers with the view of effecting a more perfect combustion of the inflammable gases, by introducing fresh atmospheric air above the bars.

Snap, is a tool used by boiler-makers for giving the head of the rivet a round and symmetrical form before it cools, but after it has been *closed.*

Snifting valve, (soupape renifiante,) is the small valve fitted to the condenser, and opening outwards for the escape of the air and steam ejected during the process of "blowing through."

Socket, (socle, crapaudine).

Solders, (soudures,) are alloys of a medium degree of fusibility, employed for joining metals together. "Hard solder" for brass is formed of 3 parts copper, 1 part zinc: soft solder for brass, of 6 parts brass, 1 part tin, 1 part zinc. A common solder for iron, copper, or brass consists of nearly equal parts of copper and zinc.

Sole plate, base plate, or *foundation plate,* (plaque du fond,) is the strong

plate which is bolted on the engine bearers, and forms the foundation for the engine.

Spanners, are the keys used for screwing up nuts.

Spare gear, (pièces de rechange,) are carried in Government and other steamers, to replace any portions of the machinery which may be broken or injured at sea.

Speed, (vitesse).

Spindle, (axe, verge).

Split pins, are those which have a thin wedge of steel inserted in the end to prevent their falling out.

Springs, (ressorts).

Spring balance, (balance à ressort,) is a spiral-spring weighing balance fitted with steam-tight piston, index plate, and pointer, for showing the pressure of high steam.

Spring beams (traversins de roues,) are wooden beams stretched between the ends of paddle-beams to support the bracket for the outside bearings of paddle-shaft.

Square; square foot, (quarré; pied carré).

Square tuck, is the flat surface left at the stern of a vessel when the planks of the bottom are not worked round to the wing transom, but end in the fashion-piece.

Starboard engine, (machine de tribord,) is that on the right-hand side of the vessel when looking towards the bow.

Starting gear, (encliquetage régulateur,) for starting the engines, comprises a wheel for working the slide valves by hand, and at the same time bringing the eccentric into gear, so as to continue the motion of the valves; a handle to open the throttle-valve, and admit the steam; one to open the blow-through valve, and another to admit condensing water through the injection-cock.

Steam engine; steam boat, (machine à vapeur; bateau à vapeur, pyroscaphe).

Steam chest, (réservoir pour la vapeur,) is the reservoir for steam above the water of the boiler.

Steam room, (espace pour la vapeur,) is the capacity for steam over the surface of the water in the boiler.

Steam gauge, mercurial, (manomètre pour la vapeur,) is employed to show the pressure of steam in the boiler by marking the height to which it will raise a column of mercury in a siphon tube.

Steam-tight, (étanche de vapeur).

Steam tug, (bateau remorqueur).

Steel, (acier).

Steersman, (timonier).

Stern, (poupe).

Still or *dead water*, (eau morte).

Stop valves, or *communication valves*, (soupapes d'arrêt,) are fitted in the steam pipes where they leave the several boilers, and in the connecting pipes between the boilers, in such a manner that any boiler or boilers may be shut off from the others, and from the engines.

Stops or *snugs of eccentric*, are the catches on the eccentric pulley and intermediate shaft, for the purpose of communicating the motion of the shaft through the eccentric to the slide valves, either for going ahead or astern.

Stow goods, to, (charger des marchandises).

Straight line, (ligne droite).

Strain, (effort).

Stroke of the piston, (course du piston.)

Stuffing-box, (boîte à étouffe, le collet,) is the mechanical arrangement by which a rod passes steam-tight through the cover of a cylinder or air-pump, etc. This is effected by the rod being surrounded at that place by a packing of hemp or gasket, which is compressed by means of the collar (with its *brass*) being screwed tight down upon it. The stuffing-box is lubricated with oil or melted tallow, which is poured

into the cupped collar surrounding the rod.

Sucking pump, (pompe aspirante,) is one which raises water by exhausting the air from the barrel of the pump, into which the water is forced by the external pressure of the atmosphere.

Suction pipes, (tuyaux à succion, suçoirs).

Super-heated steam, is steam whose temperature has been raised after it has left the water from which it was generated.

Supplementary engine, see *Auxiliary engine*.

Surcharged steam, is steam which has an excess of heat beyond that due to its pressure merely.

Siphon oil cups, are those fitted with a wick of cotton or worsted hanging over the edge of a little tube in the middle of the cup, the oil rising in the wick by capillary attraction, and dropping down the tube on to the bearing.

Tallow; oil, (suif; huile).

Taps and *dies*, (filières,) are employed for forming the threads of internal and external screws. The former is a hard steel screw, grooved from end to end, so as to present a cutting section, and slighly tapered. This is turned round by hand, inside the nut, by means of the *tap wrench*. Dies are screwed nuts of hard steel, grooved in the same way, for cutting the threads of bolts.

Template, (of a base plate, for instance,) is a model or gauge of it in thin sheet iron or wood, having the bolt holes cut out, and the various centres marked, for the purpose of transferring them to the hull of the vessel.

Test cocks, see *Pet cocks*.

Thread of a screw, (filet d'une vis).

Throttle-valve, (soupape régulateur,) is situated in the steam-pipe, close to the slide-valve casing, and is used for regulating the flow of steam, which in the marine engine is done by hand.

Ton equals 2240 lbs.; the French *tonne* equals 1000 kilogrammes, or 2204·86 lbs. avoirdupois.

Travel of the valves, (course du tiroir,) is synonymous with their *stroke*.

Trunk-engine, is one in which the end of the connecting rod is attached to the bottom of a hollow *trunk* fitted to the upper side of the piston, and alternating with it through the interior of the steam cylinder. The trunk itself passes steam tight through the cylinder cover, by means of a stuffing-box.

Trunnions of oscillating cylinders, are the hollow axes upon which they vibrate, and through which the steam passes into the belt which leads round the exterior of the cylinder to the valve casing.

Tubular boilers, are those in which the flame and hot gases, after leaving the furnaces, pass through a great number of small iron or brass tubes surrounded with water.

Tube-plugs, formed of hard wood, are used for driving into the two ends of a tube that has been burst by the pressure of the steam, as a temporary remedy until a new tube can be put in.

Tug, or *towing boat*, (remorqueur).

Two-way cock, (robinet à deux eaux).

Up-take, is the name given to the flue of a boiler into which the others are gathered at the end of their course, and thus *taken up* into the foot of the chimney.

Vacuum gauge, or barometer, (baromètre,) is fitted to the condenser to show the vacuum.

Vacuum pump, (pompe à vide,) is sometimes fitted to the boilers for the purpose of filling them above the level of the sea, by withdrawing the air from the inside of the boiler, when the water will of course rise,

by the atmospheric pressure outside.

Vacuum valves, see *Reverse valves*.

Valves, (valvules, soupapes, clapets, tiroirs).

Valve casing, (boîte du tiroir, boîte à vapeur,) is the cast-iron chest enclosing the slides.

Valve-gearing, (armature du tiroir).

Velocity, (vitesse).

Wages, (gages, salaire).

Washers, (rondelles,) are the round pieces of thin iron or brass interposed between the nut of a bolt and the surface upon which it is screwed down.

Waste-steam pipe leads from the *valve chest* on the top of the boilers, to carry off the steam escaping through the safety valves.

Waste-water pipe, see *Discharge pipe*.

Water gauges, namely, *glass water gauge* and the *brass gauge cocks*, are attached to the front of the boiler for showing the level of the water.

Water-tight, (étanche d'eau).

Wear, (usure).

Wedge, (coin).

Weigh-shaft, is the rocking shaft used in working the slide valves by the eccentric.

Wet steam is steam which holds watery particles in mechanical suspension.

Worm wheel, is a wheel with teeth, formed to fit into the spiral spaces of a screw, so that the wheel may be turned by the screw, or *vice versâ*.

THE END.

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